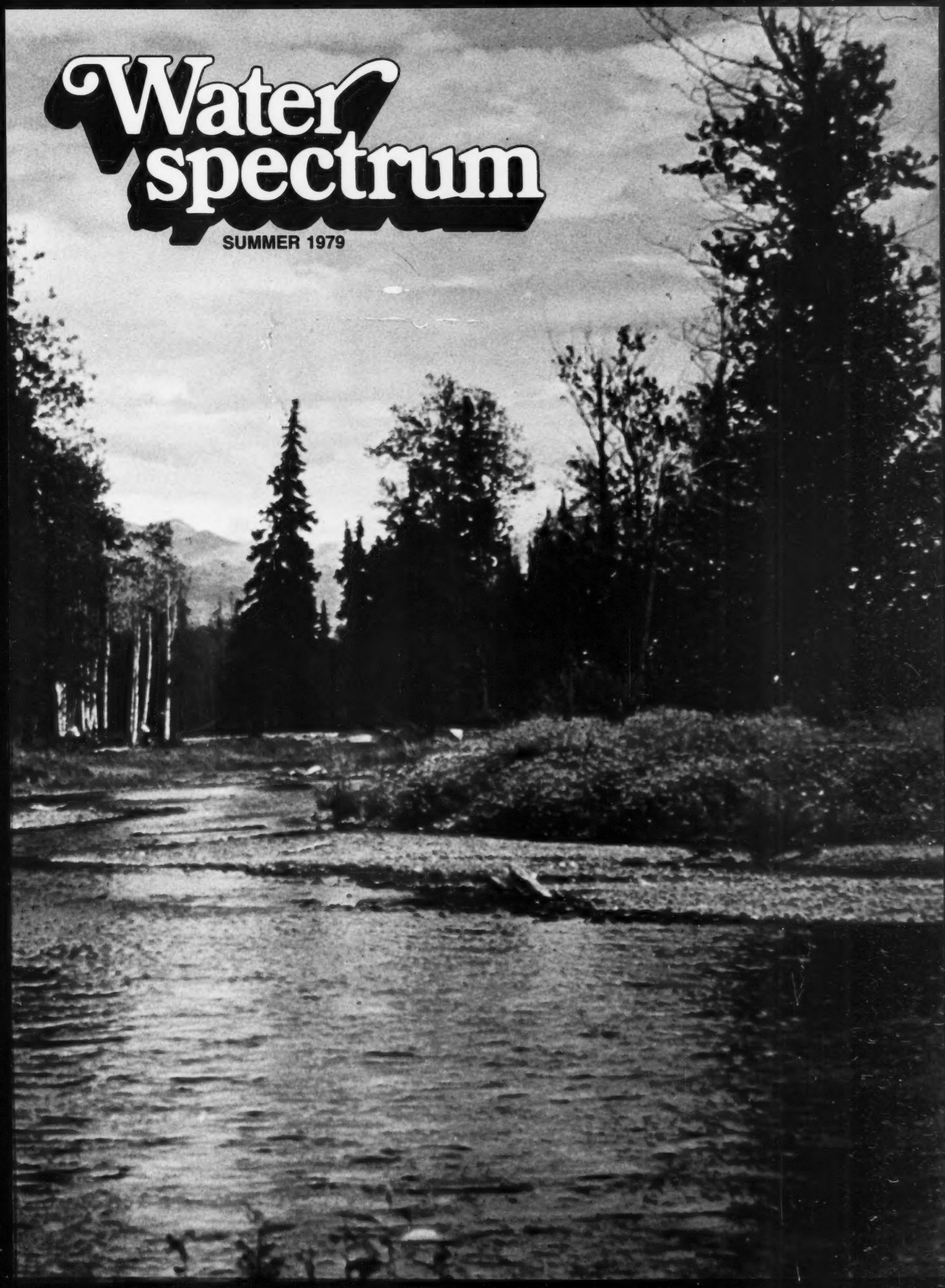
Water spectrum

SUMMER 1979



Water spectrum

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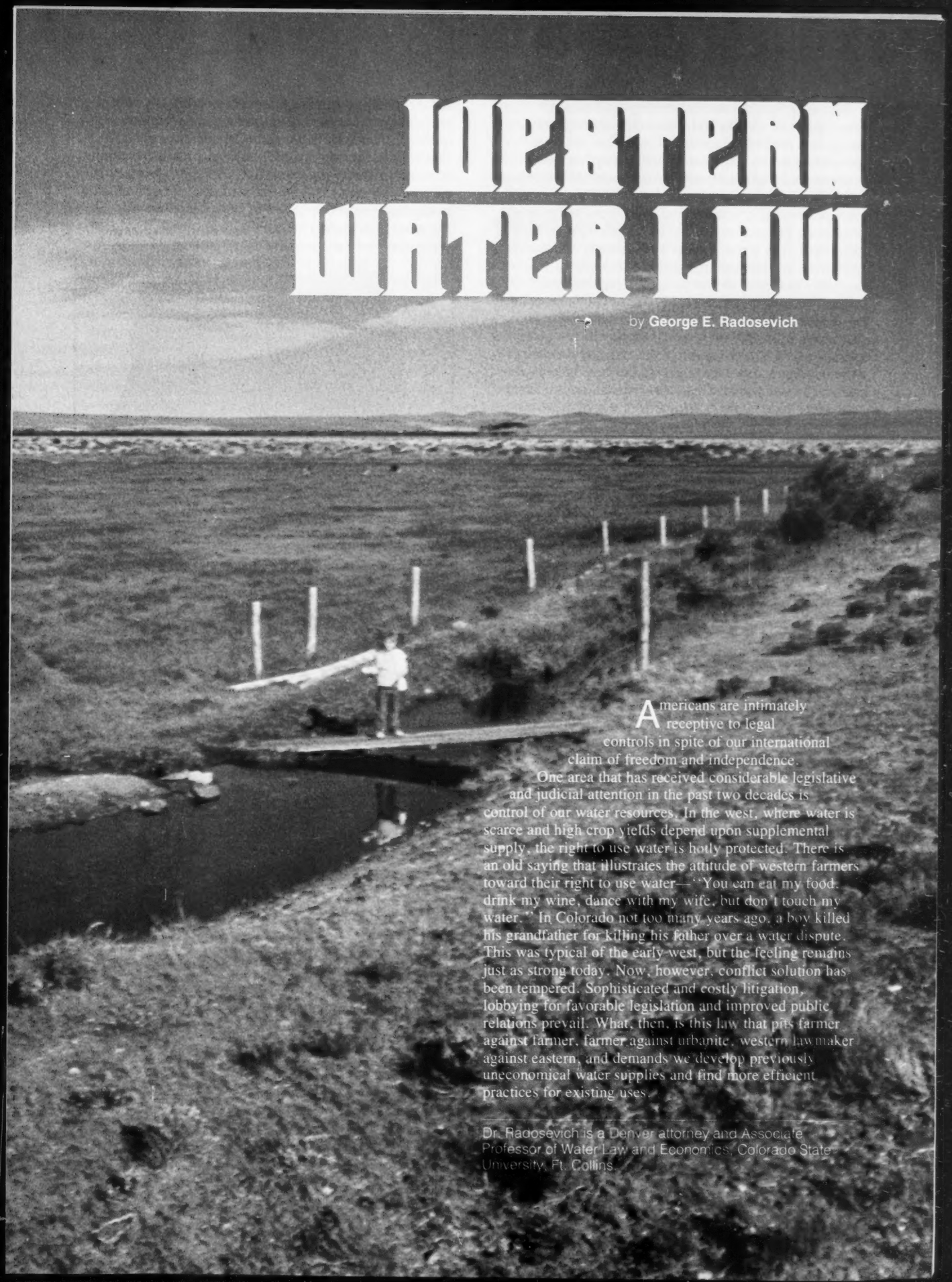
WESTERN WATER LAW

by George E. Radosevich



Americans are intimately receptive to legal controls in spite of our international claim of freedom and independence. One area that has received considerable legislative and judicial attention in the past two decades is control of our water resources. In the west, where water is scarce and high crop yields depend upon supplemental supply, the right to use water is hotly protected. There is an old saying that illustrates the attitude of western farmers toward their right to use water—"You can eat my food, drink my wine, dance with my wife, but don't touch my water." In Colorado not too many years ago, a boy killed his grandfather for killing his father over a water dispute. This was typical of the early west, but the feeling remains just as strong today. Now, however, conflict solution has been tempered. Sophisticated and costly litigation, lobbying for favorable legislation and improved public relations prevail. What, then, is this law that pits farmer against farmer, farmer against urbanite, western lawmaker against eastern, and demands we develop previously uneconomical water supplies and find more efficient practices for existing uses?

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Globally, there are two political systems of water law—national* and Federal. From the very beginning, we recognized the Federal system of water law: the jurisdiction over water quantity and quality is divided between the Federal and state governments. At the national level, the Federal government exercised certain control, such as interstate commerce and navigation, and reserved proprietary interests over water on certain types of Federal water laws. The water laws for both quantity and quality control are uniform and nationwide with regional flexibility in the implementing agency regulations.

The Federal government holds title to public lands in all the western states, and many of those lands were withdrawn from entry or reserved for specific purposes; for example, Indian reservations, parks, national forests and monuments, and oil shale reserves. On these lands, sufficient water was also reserved, from allocation under state laws, to carry out the purpose for which the lands were set aside under what is now popularly called the Federal Reservation Doctrine.

At the state level, each state is entitled to adopt its own system of water law over waters arising within its jurisdiction, but not to conflict with Federal laws. As local customs developed and states were formed, each state adopted its own particular system of water law. Consequently, there are significant variations for *quantity* control of water among the states. State water *quality* control laws are more uniform, however, and follow a pattern set by Federal legislation.

The evolution of state water quantity laws was simple and direct. They were a consequence of climate, water availability, source and need, and reflected the state of technical knowledge of the time. Surface water laws developed along two distinct philosophies which were consistent with the geo-climatic condition of the state. In the humid eastern half of the country and along the west coast, the riparian (''adjacent to'') doctrine was adopted. The more arid western half of the country was faced with

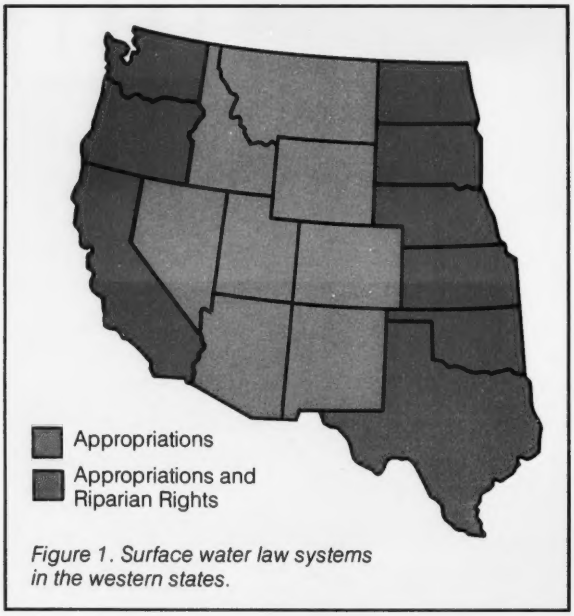
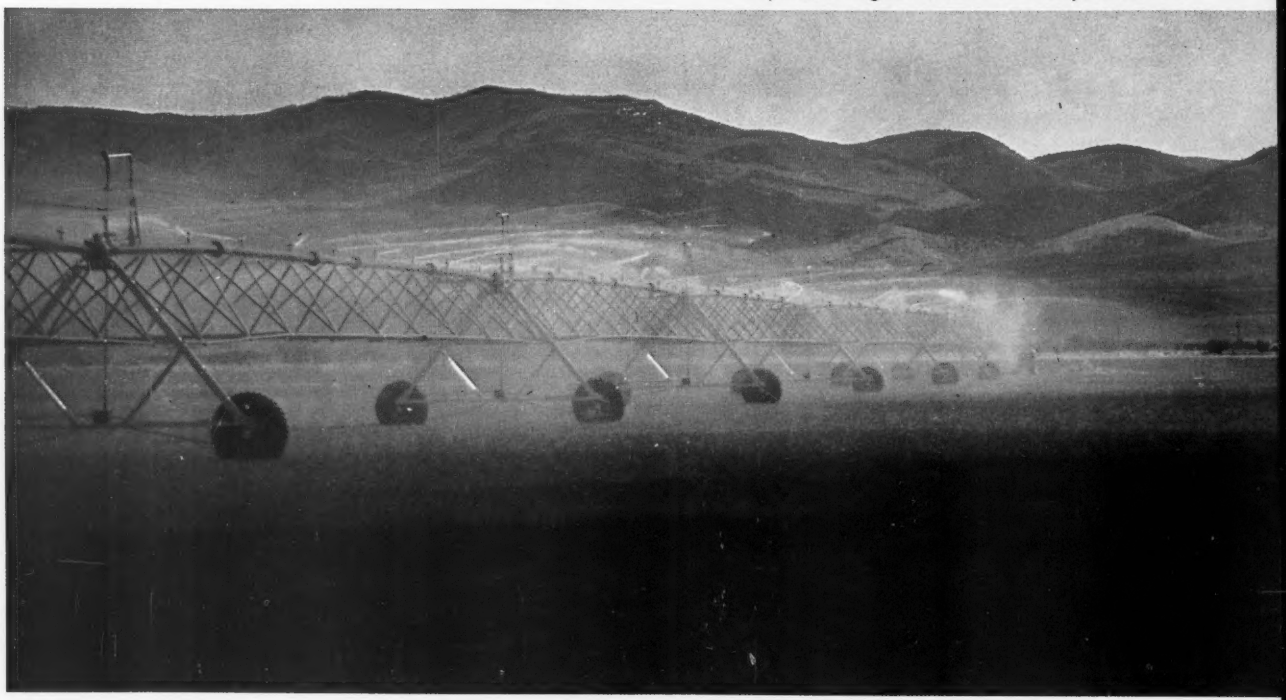


Figure 1. Surface water law systems in the western states.

*A ''national'' system of water law exists where the national government has complete authority over the water resources under a nationwide water law.

Sprinkler irrigation, San Luis Valley, Colorado.



an immediate problem of deciding how to allocate the scarce resource and thus was compelled to develop a system of law peculiar to arid lands. From trial and error, compromise and an infusion of water law customs brought into the country by immigrants, emerged the doctrine of prior appropriation. Some states, having a varied water availability, adopted a mixed riparian/prior appropriation system. Despite the classification of state systems into these three groups, there is a wide variation between states following the same doctrine as to the manner for determining water rights, exercise of the right, water use efficiency criteria, procedures for obtaining water rights, and administering and enforcing the law.

(Ground water legislation occurred much later, due in part to the lack of knowledge of subsurface supplies and in part to adequate surface supplies. The basic principles of use and control often followed the surface doctrines, but again each state adopted and modified the law to fit its particular needs.)

The water laws and administrative mechanisms of the western states can be classified as "use-oriented"; the dominant objective being to use the water to produce an economic gain. To many this meant a livelihood and to others a profitable venture. Fig. 1 illustrates the particular surface water system adopted by each western state. With time, the overlapping jurisdiction at Federal and state levels, the fugitive nature of water and complex interstate stream systems and agreements, population shifts and new water demands in the west—drawing the use of water away from traditional agricultural uses to industrial and energy production uses—has brought about the current crisis between Federal and state water policies and laws.

Water and the Western Law

Without water the arid west would have limited productive capability, at least from the agricultural point of view. To fully appreciate the western attitude toward water rights, one must recall that agriculture was promoted by the Federal government as the future of the west. Through the multitude of Federal policies, law and programs, people were induced to settle with the assurance that their use of water would be protected. Private and government investments were based upon the security of a continued right to divert water under the various state laws. As such, agriculture became the major user of diverted water in the west, accounting for 90 percent of water consumption. Within this agricultural economy, one finds meadows flood-irrigated for cattle raising and water pumped or diverted from streams to fields producing high cash value and forage crops.

The 17 western states have adopted one or both of the basic water quantity law doctrines found in the United States. The rule adopted by every western state is the doctrine of prior appropriation, with those states on the

Production of high cash value crops, Mesilla Valley, New Mexico.

western seaboard and from North Dakota to Texas also applying the riparian doctrine to lands adjacent to natural water bodies. There is a definite trend to eliminate the riparian doctrine as demands on surface water increase. For all practical purposes, most of the dual-doctrine states have relegated the riparian system of surface water control to an insignificant role and thus only a brief explanation will be provided of the doctrine.

Those states in the west applying the riparian doctrine follow the American Rule of Reasonable Use. Under this rule, riparian landowners can divert a reasonable amount of water with respect to all other riparians on the stream; under certain conditions, nonriparians may make a reasonable use of remaining waters.

States following the riparian doctrine recognize water as a public resource, held in trust by the state for use by the people of the state. Thus, a landowner whose land borders a stream does not have an ownership right to the waters of the stream, but rather only a fundamental right to a reasonable use of the water by virtue of his land location. He is protected from harmful, unreasonable uses by others. The riparian is essentially a co-user with all other riparians on the water source. Between riparian uses, priority of use does not establish priority of right in times of decreased flow. Consequently, his right to use water is not a right for a fixed quantity of flow or volume, but rather is a correlative right dependent largely upon the extent of development that takes place.

The riparian right exists perpetually, even without use, while the land remains adjacent to the water source. Most states prohibit selling or transferring of riparian rights and some even limit the size of riparian land to the smallest remaining tract of the original patented holding. Because riparian rights lack precise definition and are a part of property rights in land, no administrative system was incorporated into the doctrine. If someone complains of a misuse by his neighbor, he has to go to court to protect his right.

Recent changes in law have resulted from the inability of existing water supplies to meet expanding demands on one side, and a recognition of the public interest in water resources on the other. The results generally have been the establishment of a permit system to allocate water among users and creation of administrative machinery to assess and control water resources through the permit system. Among the western states, modifications are strongly influenced by the simultaneous application of the prior appropriation doctrine, and increased demands on surface supplies for in-basin as well as out-of-basin use stimulated in part by large-scale reclamation projects and heavy reliance upon ground waters in some states, i.e., California, Nebraska, Oklahoma and Texas. In all of the dual-doctrine states except California, new claims to the use of surface waters must comply with the statutory requirements of the prior appropriation doctrine.

The doctrine of prior appropriation exists in all of the 17 western states in some form, and like most popular principles, its origin is shrouded by controversy. Some say it evolved out of the mining camps of California, or was introduced by the Spanish or other early settlers of the west.

Evolution of this doctrine was a fortunate event for it proved as useful for agriculture as for mining. As mining became more competitive, many miners and newcomers to the area began farming. The doctrine protected the first settler to use water on his land. Latecomers had to respect the prior ownership of land and the amount of water which

Flood irrigation of vineyards, Southern California.

the prior settler was using. Hence the cliche "first in time, first in right." Although there are many variations between the appropriation doctrine states, a number of key principles exist to establish commonality, if not relative uniformity, among them:

- There had to be a diversion from a natural stream or body of water. This has been relaxed in most western states during the last decade to allow in-stream use for recreation, fish and wildlife protection.
- Water must be applied to a beneficial use. Initially, this was legally defined to be domestic, municipal, stock watering, irrigation, and certain industrial and power uses. In most of the western states, however, the rural representation insured agriculture a high position as a beneficial user. Beneficial use also referred to the nature of use, and will be discussed later.
- When a diversion and application of water to beneficial use was completed, a water right was created. This right entitled the holder to continued use, as long as the use was beneficial.
- Every water right acquires a priority date such that priority of right and not equality of right is the basis for distributing water.

Drain for return flows, Grand Valley, Colorado.

The doctrine of prior appropriation is based upon the allocation of water under the concept of a property right interest in water. Simply put, this doctrine creates the right of private use of a public resource under certain conditions, and for uses that have been declared to have a public interest. The right does not automatically exist by virtue of the presence of water upon, flowing through, or under land. In all western states, waters are declared to be the property of the public, people or state. Regardless of whether the state or the public (people) own the water, the state is a trustee for the proper allocation and distribution of water and administration and implementation of state water laws.

The right so acquired has two legal characteristics. First, the right itself is a real property right. It is an exclusive right, which like other property interests, can be defined, is valuable and can be sold, transferred, mortgaged, or bequeathed.

The second characteristic is that it is a usufructory right and can only be exercised when water is available and can be put to beneficial use. There is no absolute ownership in the water itself prior to diversion. This water is still a public resource, and if the right holder cannot put it to beneficial use, he must allow it to flow past his point of diversion to other appropriations. However, if he can use the water and he is in priority, the water diverted into his delivery system is his personal property until it returns back to the stream or escapes his control.

Saline drainage, Welton-Mohawk Irrigation District, Arizona.

The water right under the appropriation doctrine consists of several elements that give value, dependability and security to the holder. (See Fig. 2, left) The right exists in a definite source of supply; has a definite point of diversion; is for a fixed and stated quantity; is for a specific type and place of use, which together implies the annual time of use; and, assures the holder of at least an implied protection of the maintenance of water quality necessary to carry out the purposes for which the water was appropriated.

As previously stated, one of the key principles to the prior appropriation doctrine is the "priority of right" that is granted to a user over subsequent appropriations. It is most often this priority date, coupled with the dependability of flow in a stream and location of point of diversion that gives water right its value. In most states, the priority date is the date the application for a water right is received by the state water agency. This agency, often called the State Engineers Office or Department of Diversion of Water Resources, is responsible for administering water right to a variety of categories of users and implementing the states' water law through local water masters. (See Fig. 2, right)

Several systems were developed by the states to allocate water and provide evidence of water rights, including posting a notice at the point of diversion and filing a record with the county clerk. The predominant approach now is the permit system. An application is filed with the appropriate state agency which then evaluates and determines its disposition—based upon availability of unappropriated water and nonimpairment of existing rights. If approved, a permit is issued which may contain conditions of use. If denied, the applicant is entitled to judicial review of the administrative decision. The finalized water right recordation may be called a licence, certificate or decree. A few states have different classes of permits which greatly enhance their ability to allocate and regulate the use of water among competing interests. In Texas, for example, there are eight classes, from emergency not-to-exceed 30 days use to year-round perpetual rights.

The cornerstone of water allocation under western law is that "beneficial use is the basis and measure of the right to use water." This is often the extent of definition found in state water laws. The concept has two aspects. In order to use water, it must be taken for beneficial purpose. The other aspect is the use of water itself must be beneficial and carried out in a beneficial manner. One state, for example, allows only the allocation of that amount "economically necessary for the purpose authorized when reasonable intelligence and reasonable diligence are used in applying the water to that purpose."

In addition to the requirement that water will be allocated to a user for beneficial use, many states have adopted criteria to be followed in allocating water to agriculture. This criteria is commonly referred to as the statutory duty of water. Little uniformity exists between states, again indicating the different geo-climatic conditions found throughout the west. Water used by irrigated agriculture may be used and reused a number of times as it goes through the diversion, application and removal stages; irrigation return flows can occur from seepage, deep percolations and tailwater runoff. (See Fig. 2, center) This dynamic process of water use and return flow gives rise to the adage that one man's waste water (return flow) is another's water supply. Rights to continued use of return flows, should they continue to occur, can be acquired.

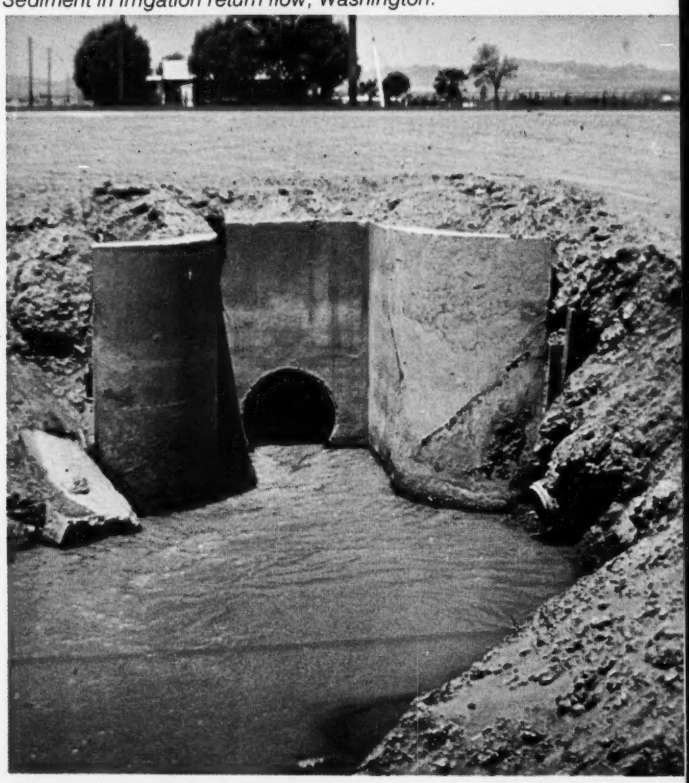
One other aspect of the water right that is often overlooked by those not familiar with the doctrine is that it must be exercised, otherwise it can be lost, totally or partially, through non-use or misuse. The procedure for losing the right is through abandonment or statutory forfeiture. In addition, the right may be condemned for domestic use by municipalities or lost through adverse possession by another user. In order to protect the right, the holder is compelled to divert his full entitlement, often without regard to possible adverse consequences to other users of junior priority or downstream location.

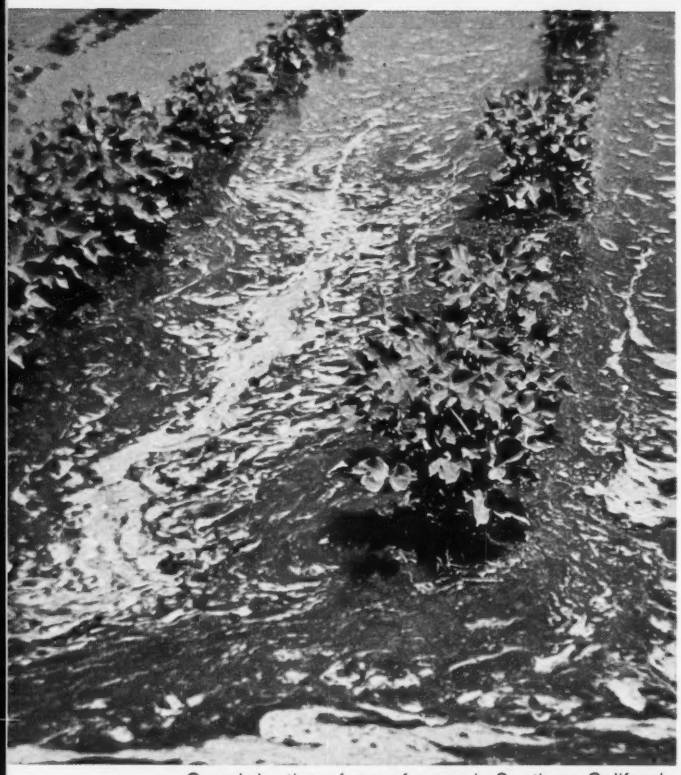
Issues and Problems

The water laws in the western states have changed considerably since the late 1800s as new demands and changing conditions created challenges to the old laws and new lawmakers. An examination of the historical growth of the region during that period ties many changes in the law to new Federal and state development policies and the emergence of the public interest.

Throughout the first half of the 20th century, the country was bent on rapid reclamation of arid lands. Surface water laws experienced some changes during this time. In the

Sediment in irrigation return flow, Washington.





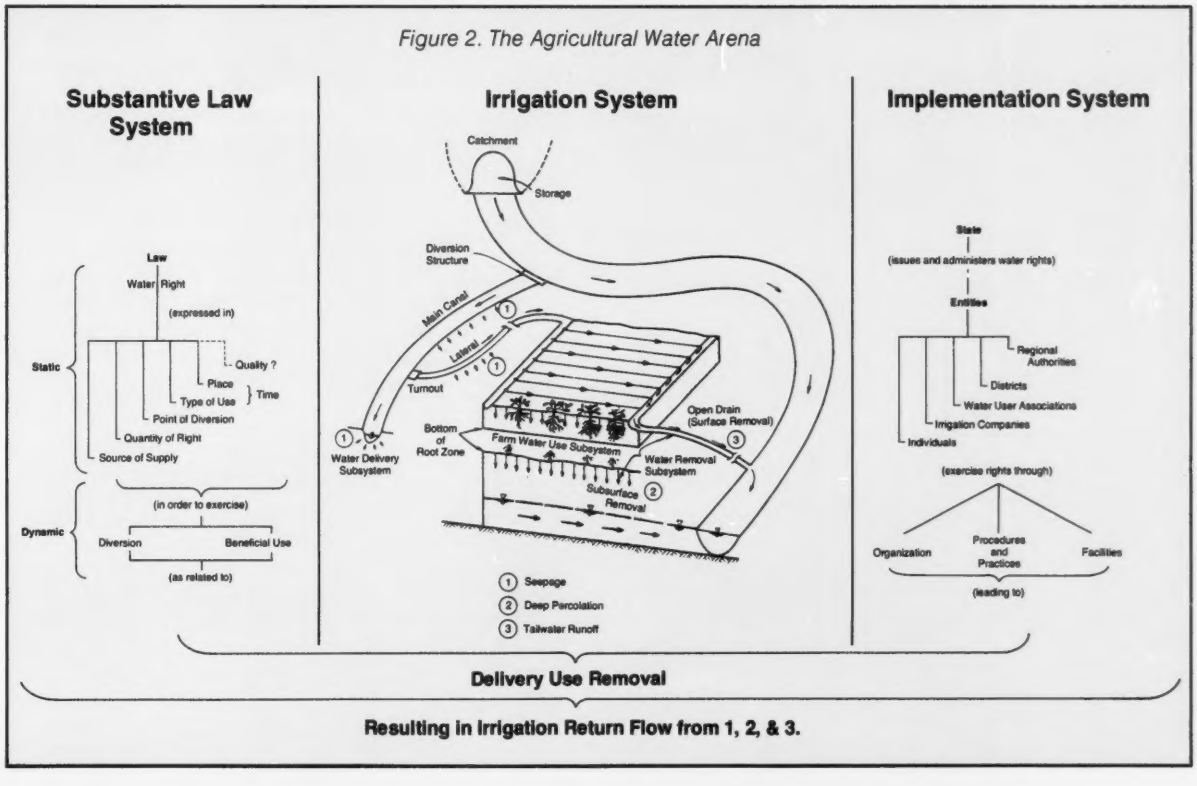
Over-irrigation of row of crops in Southern California.

50s, ground water development rose considerably as rural electrification programs made it possible to pump water with less cost and human effort. During this time, ground water laws received the most attention in the state legislatures.

Throughout the 60s, the nation took a look at the extent of development and began to adopt new policies oriented toward management of the resource. The environmental ethic emerged in the late 60s and early 70s, and caused another harsh look at the natural resources laws, particularly their inconsistencies. In several western states, the effect of tributary ground water withdrawal upon surface flows began to receive serious attention by water users, courts and lawmakers. Also during the 60s and 70s reevaluation of water law administration and water quality control resulted in statutory changes at the state and Federal levels.

The first basic problem now facing water administrators in the west is how a finite resource, with its fugitive and hydrologic characteristics, will meet the infinite demands placed upon it. In most western states, all available surface water is appropriated to existing or future use. Where unappropriated water exists, there are few modern policy guidelines at the state level to assist water officials or courts in setting priorities for allocation between competing applicants. Most western states allow for reallocation of water to other types, places and times of use with the transfer, often brought about by the force interplay of the market system. As energy developments, shifting and expanding populations, and other new water

Figure 2. The Agricultural Water Arena



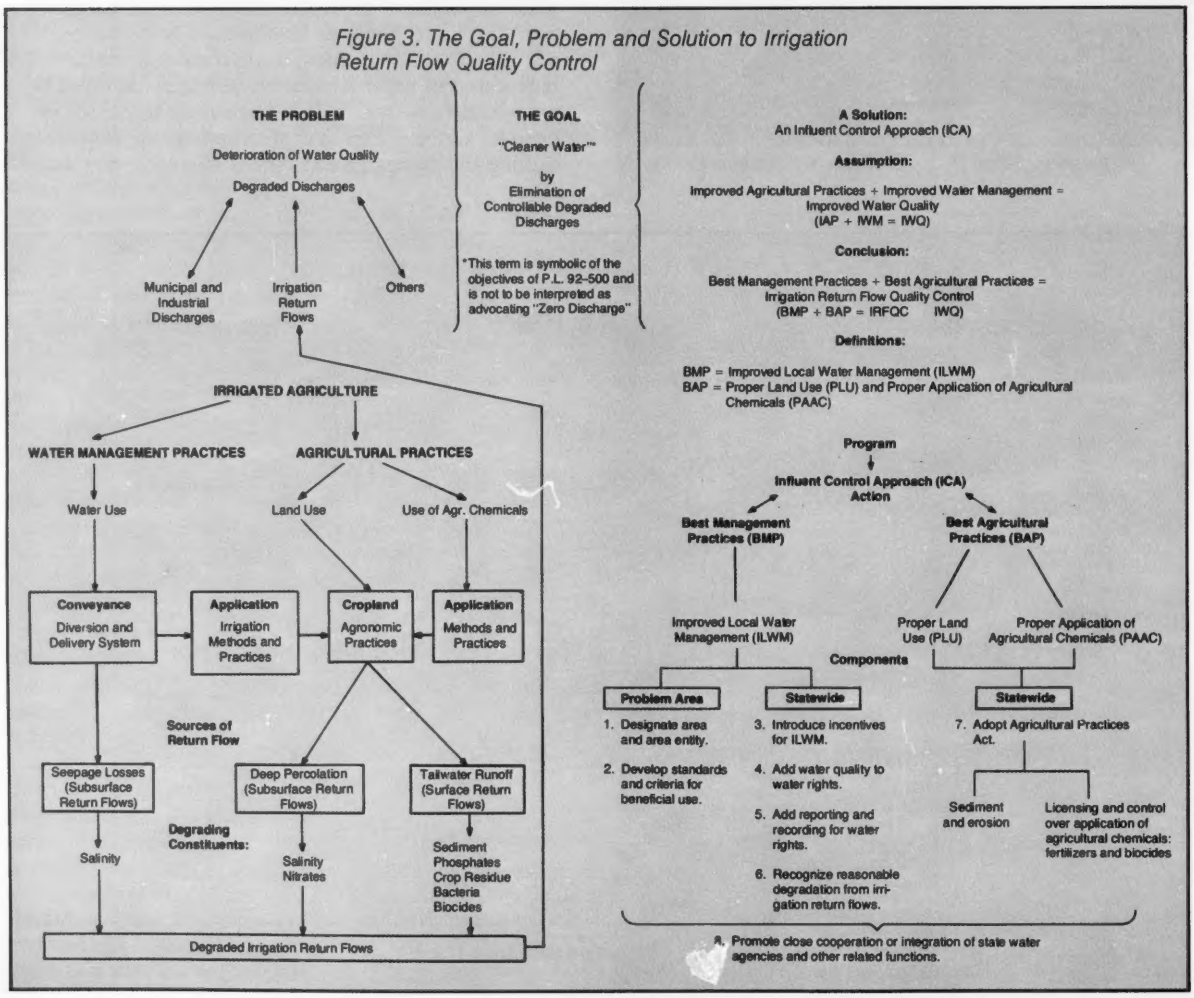
users place demands on the particular geographic location, the economic system often dictates the reallocation of the resources. Because agriculture holds the rights to the vast majority of available water in the west, most reallocation is at the expense of food or livestock production. Interbasin transfer and more efficient water use practices are strongly promoted to offset the transfer from agricultural uses.

The second dilemma that vested water users are rapidly facing is the allocation of surface and ground waters under laws that were not cognizant of the interdependence of these two water sources. The hydrologic connection did not become apparent until groundwater pumping began to affect the water table supporting the surface water supply. In several states, e.g., California, Colorado, New Mexico and Texas, conjunctive use of the surface and ground waters has received much attention as surface users seek to protect their rights from the invisible invasion of the pumpers.

When water law first became a topic of western state legislation, quantity—for agriculture—was the big issue. However, as large volumes of water were allocated and degraded and return flows from all uses began to exceed

Over-irrigation of wheat resulting in poor crop yield, Nevada.

Figure 3. The Goal, Problem and Solution to Irrigation Return Flow Quality Control


THE PROBLEM
Deterioration of Water Quality
Degraded Discharges
Municipal and Industrial Discharges
Irrigation Return Flows
Others
THE GOAL
"Cleaner Water"*
by
Elimination of Controllable Degraded Discharges
*This term is symbolic of the objectives of P.L. 92-500 and is not to be interpreted as advocating "Zero Discharge"
A Solution:
An Influent Control Approach (ICA)
Assumption:
Improved Agricultural Practices + Improved Water Management = Improved Water Quality
(IAP + IWM = IWQ)
Conclusion:
Best Management Practices + Best Agricultural Practices = Irrigation Return Flow Quality Control
(BMP + BAP = IRFQC IWQ)
Definitions:
BMP = Improved Local Water Management (ILWM)
BAP = Proper Land Use (PLU) and Proper Application of Agricultural Chemicals (PAAC)
IRRIGATED AGRICULTURE
WATER MANAGEMENT PRACTICES
AGRICULTURAL PRACTICES
Water Use
Land Use
Use of Agr. Chemicals
Conveyance
Diversion and Delivery System
Application
Irrigation Methods and Practices
Cropland
Agronomic Practices
Application
Methods and Practices
Sources of Return Flow
Seepage Losses (Subsurface Return Flows)
Deep Percolation (Subsurface Return Flows)
Tailwater Runoff (Surface Return Flows)
Degrading Constituents:
Salinity
Salinity
Nitrates
Sediment
Phosphates
Crop Residue
Bacteria
Biocides
Degraded Irrigation Return Flows
Program
Influent Control Approach (ICA)
Action
Best Management Practices (BMP)
Best Agricultural Practices (BAP)
Improved Local Water Management (ILWM)
Proper Land Use (PLU)
Proper Application of Agricultural Chemicals (PAAC)
Components
Problem Area
Statewide
Statewide
1. Designate area and area entity.
2. Develop standards and criteria for beneficial use.
3. Introduce incentives for ILWM.
4. Add water quality to water rights.
5. Add reporting and recording for water rights.
6. Recognize reasonable degradation from irrigation return flows.
7. Adopt Agricultural Practices Act.
Sediment and erosion
Licensing and control over application of agricultural chemicals: fertilizers and biocides
8. Promote close cooperation or integration of state water agencies and other related functions.

the assimilative capacity of streams and lakes—now aggravated by decreased flows from diversions—the Federal government adopted a major water quality control policy and program. This took place in response to the Federal Water Pollution Control Act of 1972 (P.L. 92-500), which preempted state control over water quality and set out the means and procedures for bringing our nation's waters back to "swimmable and fishable" conditions.

Unfortunately for the west, the Federal law and implementing regulations were adopted without proper consideration for how they would interface with existing state quality laws. Such is the case of water quantity/quality control by separate laws at different government levels and implemented by unrelated agencies. And therein lies the third rub. Fig. 2 illustrates the relationship between the water quantity law and the irrigation system. Directly affecting the return flow is the water right designed to provide the water user with the same constitutional guarantees extended to real property. He is subject to certain rigidities in the exercise and protection of this right which inhibit adoption of more efficient practices. Furthermore, he is primarily concerned with his immediate geographic area and unaware of the effects of exercising his right upon downstream users who may be in another state and themselves subject to different rules and regulations.

The fourth dilemma is the intergovernmental conflict that has occurred between the Federal and state governments since the early 1900s. This conflict reached new highs with alleged intervention of Federal control through proposed national water policies and the new applications of the Federal Reserve Doctrine. In Colorado recently, the Colorado Water Congress concluded that unwarranted Federal intrusion is the premier water problem. In addition, major issues are being raised over the adequacy of existing interstate compacts for surface water, need for compacts between states covering interstate groundwater bodies, and interstate transportation of water in energy related matters.

Finally, a concern in the western states is the rise in litigation to solve problems. There is a noticeable tendency to resort to litigation as the initial solution. Also of concern is the complexity of the litigation and judgments. Often water users are required to expend considerable financial resources to protect their rights, due to the adoption of poorly constructed legislative mandates and agency regulations.

What the Future Holds

As complex as the water law systems are in the west, any situation taxing the ability of current water supplies to meet increasing demands will require changes in the laws. Many constraints to improved water use and management lie in these water rights laws. Generally, it is concluded that they lack specificity in definition, provide an ad hoc approach to resolving key water problems through the courts, insure that the property right concept will continue to be a critical roadblock to curative solutions, and generally recognize customary standards of the community as criteria for diversions and conveyance facilities.

It is also demonstrable that some state laws fail to require the adoption of viable recordation systems for water rights, fail to integrate water quantity and quality control, and, finally, fail to provide incentives for recapturing and properly using return flows.

To systematically attack the water management problem—particularly the return flow quality problem—changes in state laws must include efforts to achieve uniformity between inter- and intra-state laws and administration. Criteria must be developed for efficiency in allocation and use, and this criteria applied to all use—private and public. Lawmakers must recognize and promote "public trust" in water agencies, and "public duty" in the user. They should specifically incorporate the element of water quality in water rights, and shift to a term permit or periodic evaluation of effective water use.

Finally, a program of Influent Control Approach for irrigated agriculture must be adopted that includes outflow analysis. The Influent Control Approach is based on the assumption that improved water management, plus improved agricultural practices, will significantly contribute to improved water quality. And, that best management practices, plus best agricultural quality control, will, in turn, contribute significantly to the national goal of cleaner water through improved quality. (Fig. 3).

The western states have moved a long way toward developing and managing their water resources. But the challenge of the future, if water supplies are to meet the needs of municipalities, industries, public recreation and maintenance of a strong agricultural/energy base, requires constant effort to improve the institutional framework for water and related resources management. ■

Saline soil conditions causing loss of field production, Mesilla Valley, New Mexico.

WILDLIFE HABITAT IMPROVEMENT: SOME OPTIONS

These multi-level intakes at Oroville Dam, California, are of the variable level design. Temperature control is provided by steel shutters which can be lowered from the storage bays at the top of the dam. Downstream water temperatures can be geared to the needs of a particular fish species.

by Gerald C. Horak and James E. Olson

As previously discussed in *Water Spectrum,* the Habitat Evaluation Procedures (HEP) will provide an assessment and evaluation tool to help project planners identify mitigative or compensative measures and affix relative value to the fish and wildlife resources that will be affected by water project development. Various combinations of operational and management practices may be considered to identify which possibilities will best fulfill mitigation/compensation requirements. The identification of fish and wildlife measures to be included in mitigation/compensation plans during project planning, design, construction and operation, requires data on the range of possible measures, as well as a discussion of their purpose, design, limitations, effectiveness and cost. This article will address some of those options. *(For a description of the HEP methodology itself, see Water Spectrum, Spring 1979.)*

Because no comprehensive evaluations of the success of implemented fish and wildlife measures had been completed, the Western Energy and Land Use Team, Office of Biological Services, U.S. Fish and Wildlife Service (FWS) awarded a 1976 contract to Enviro Control, Inc. to fulfill this need. The broad purpose of the research was to document successful and potentially successful habitat and population improvement measures accompanying water resources development projects. The projects of primary interest were dams and reservoirs in the western U.S., including diversions and canals. The measures considered generally involved structural and operational features as well as habitat modification and population control.

The specific study objectives of the research were:

- To identify measures that were recommended by the FWS, particularly those implemented by construction agencies, as features for improving fish and wildlife habitats and populations associated with water development projects;
- To critically evaluate the implemented habitat and population improvement measures to determine which ones were effective in producing the desired or anticipated improvement for fish and wildlife;
- To identify additional measures not necessarily recommended by the FWS or actually implemented, but believed or proven successful toward improving fish and wildlife habitats and populations; and,
- To prepare a handbook articulating the measures demonstrated to be most successful and those considered potentially successful, and identifying the best ways they can be implemented successfully.

The Western Reservoir and Stream Habitat Improvements Handbook[1] is based primarily on measures shown to be effective in the past at a representative selection of 90 dam and reservoir projects in 19 western states. (Fig. 1) First, we identified the habitat and population improvement measures recommended by the FWS for Federal water development projects currently in operation or under construction in the western states. Projects analyzed were those directly controlled by Federal agencies—the Bureau of Reclamation, Corps of Engineers, Federal Energy Regulatory Commission (formerly Federal Power Commission), Soil Conservation Service, and Bureau of Indian Affairs. These projects were among over 300 candidates proposed to the FWS. For the 90 projects the FWS selected for detailed study, we ascertained the recommended measures and the status of their acceptance and implementation. Seventy-five percent of the 432 measures recommended were incorporated in project plans.

The major effort in preparing the *Handbook* was devoted to investigation into the historical success of 286 implemented improvement measures within 60 categories. Each application of an improvement measure was classified as successful, marginally successful, or unsuccessful. If an individual measure apparently accomplished a major proportion of its intended purpose, it was classified as successful. If only a moderate part of its intended purpose was attained, it was marginally successful. A measure was deemed unsuccessful if only a minor portion of its intended purpose was realized.

Whenever possible, at least two complementary criteria for success were applied—one concerned with habitat improvement, and another with population improvement. For example, the habitat improvement criterion for a seasonal minimum instream flow might be "amount of streamflow necessary for the spawning migration of salmonids"; the population improvement criterion might

Mr. Horak is Manager and Mr. Olson is Aquatic Biologist at Enviro Control, Inc., Fort Collins, Colorado. They acknowledge the help of Lee S. Ischinger, Aquatic Ecologist, U.S. Fish and Wildlife Service's Western Energy and Land Use Team, who served as Project Officer and R. Wayne Nelson, formerly of Enviro Control, Inc., who also co-authored the Handbook described herein.

[1] Available from the Western Energy and Land Use Team, U.S. Fish and Wildlife Service, Fort Collins, CO 80521.

be "increase of juvenile salmonids in the affected stream reach." Nearly 70 percent of the 286 implemented measures were judged to be successful, and 23 percent were deemed marginally successful.

Furthermore, the guide presents measures believed to be potentially effective by investigators involved in current research or authors of recent literature. This information was obtained from a general literature review, a brief survey of research in progress, and interviews with agency staff members or research investigators.

Before the final *Handbook* was prepared, a draft was developed and technical review sessions were conducted to test and refine the preliminary handbook. Detailed critique and revision of the draft handbook was provided in three 3-day technical review sessions in Portland, Albuquerque and Denver by 53 individual reviewers, representing the FWS, the aforementioned Federal agencies, and the fish and game departments of Arizona, Colorado, Idaho, Kansas, New Mexico, Oklahoma, Oregon, Washington, and Wyoming (representatives of other states submitted written comments).

The *Handbook* discusses 60 categories of habitat and population measures. The broadest distinction within this classification scheme is between habitat and population improvement measures. Measures are classified according to their predominant purpose: however, no measure is exclusively for one purpose or the other. In this article, a sampling of five major measure categories will be discussed that have the most promise for future application, including retrofit. They are multi-level intakes, aeration-destratification, minimum flows, flow fluctuation control, and escape ramps.

Multi-level Intakes

The purpose of *multi-level intakes* is to permit selection of discharge water from various reservoir strata primarily to optimize downstream water temperatures for particular fish species. The mechanism for this purpose may be located on the dam face or within a tower in the reservoir. Intakes may be at fixed depths with closable ports, or variable-level systems with sliding shutters. Multi-level intakes can be retrofitted to existing structures as was done on Flaming Gorge Dam, Utah. Secondarily, these intakes can aid in the control of downstream water quality parameters other than temperature, such as the amount of dissolved gases and solids. Mathematical models for the prediction of reservoir thermal stratification are available to assist in the design of intake elevations and operations.

The major constraint on the use of multi-level intakes is handling the trade-offs between temperature requirements of coldwater and warmwater fisheries downstream from the reservoir outlet. Also, multi-level intakes are considerably more expensive to construct than standard discharge systems. An additional consideration in some reservoirs is the increased difficulty in screening multi-level intakes to prevent loss of fish in the released water.

Aeration-destratification of Road Canyon Reservoir, Colorado, using compressed air injection. Warmer bottom water is forced upward to melt holes in the ice cover.

The three multi-level intakes evaluated in the project investigations (New Bullards Bar Dam, California; Oroville Dam, California; and Fall Creek, Oregon) were assessed to be successful. Adjusted to 1977 dollars, the Oroville intakes cost $16,400,000; whereas $1,400,000 was required to install the New Bullards Bar multi-level intakes. In addition, the retrofitted multi-level intake on Flaming Gorge Dam cost approximately $4.5 million, according to the Bureau of Reclamation.

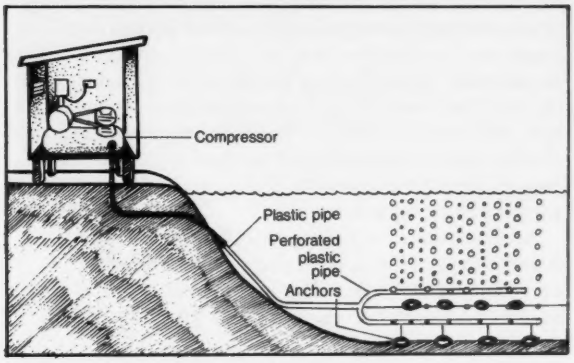
Aeration-Destratification

For reservoir conservation pools, *aeration-destratification* is an important measure. Aeration can be described as a process by which oxygen is added to or assimilated by water. Destratification is a process by which the density layering of a body of water is disrupted. By forcing the colder, denser water from the bottom of a reservoir to circulate with water from the surface, temperature and density differences are decreased, allowing wind and convection currents to further mix the impoundment. The processes of aeration and destratification are usually interdependent, i.e., when one occurs, the other follows. The extent of this, however, depends on the method used to effect aeration or destratification.

Several objectives may be met by aerating and destratifying a reservoir. Ice formation can be prevented by circulating the relatively warmer water below the surface, with that exposed to the atmosphere, to melt holes at the surface. This will benefit a winter-kill-prone reservoir by allowing reaeration from the atmosphere. Ice has also been melted to provide an open channel across a reservoir for deer and other big game to swim through so they do not become trapped by falling through the ice. Destratification will lower surface water temperatures during the summer, to reduce evaporation losses and control algae growth.

Aeration can reduce the effects of eutrophication by providing critical oxygen to the water for metabolism and decomposition. Lake productivity can be increased by circulating nutrient-rich water from the bottom strata. In addition, the quality of discharge water can be improved by aeration and destratification in the reservoir. This can benefit fish and wildlife downstream and provide better raw water for a drinking supply.

Many methods and types of equipment have been used for aerating and destratifying. The injection of compressed air is one technique. The air can be released using a diffuser such as perforated pipe anchored to the bottom of the reservoir. Some immediate aeration results from the air bubbles, but the primary function is the "chimney effect" by which water from the bottom is raised in a current established by the rising bubbles. This produces destratification and additional aeration when the water comes in contact with the atmosphere at the surface.



Stream measurements in Colorado's Yampa River to determine instream flow requirements.

Other techniques for aeration and destratification include aerohydraulic guns, water mixing pumps, liquid oxygen, surface spraying, cascade weirs in inflow streams, submerged weirs and mechanical agitators. A new method is hypolimnetic aeration. With this technique, only the hypolimnion (water below the thermocline) is aerated while the temperature regime and stratification pattern are not altered significantly. Thus it may be possible to maintain a "two-story" fishery, i.e., a warmwater fishery in the epilimnion and a coldwater fishery in the hypolimnion.

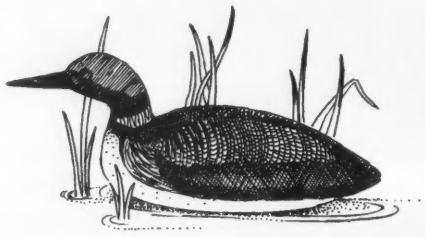
Aeration and destratification have usually been successful for increasing dissolved oxygen concentrations, decreasing levels of carbon dioxide, hydrogen sulfide and ammonia, and increasing survival and production of zooplankton and fish. Additional habitat has been provided by the prevention or reduction of inadequate oxygen levels in some reservoirs. Constraints on these procedures include the costs for equipment, materials, and operation. The labor necessary to maintain some of the devices such as pumps and compressors may be a limiting factor. Costs for aeration and destratification may be offset by reduction in the need for annual stocking due to summer or winter fish kills, the increased yield of the fishery because smaller fish can be stocked without fear of seasonal kills, and the reduced need for extensive filtering and chlorination for an adequate drinking water supply.

Another constraint is the possibility of promoting lowered oxygen levels through the resuspension of decomposing sediments. This is particularly critical during the first year of operation, though the possibility should decrease as seasons of aeration continue.

Minimum Instream Flows

Minimum instream flows—continuous, seasonal, or at specified times such as the closure of a dam—provide for fish passage upstream and downstream, maintenance and propagation of existing fish populations, and establishment of different populations than existed prior to a dam and reservoir project. Minimum flows are designed to maintain a satisfactory combination of pools and riffles for fish food production, fish cover and escape. Flows are needed especially during the summer to prevent dewatering which can result in high fish mortality from stranding in streambeds. Also, though frequently receiving less emphasis, instream flows help retain riparian vegetation and wildlife habitat and provide sources of water for adjacent ponds and wetlands.

A number of methods have been proposed to determine instream flow requirements for fish and wildlife. An excellent summary and discussion of these methods is presented by Stalnaker and Arnette (eds.) in *Methodologies for the Determination of Stream Resource Flow Requirements: An Assessment* (1976). Orsborn and Allman (eds.) in *Instream Flow Needs,* present papers from a state-of-the-art symposium on instream flow needs, emphasizing an awareness of legal, social and technical aspects of preserving minimum flows. For the most up-to-date information on instream flow methodologies, the FWS's Cooperative Instream Flow Service Group in Fort Collins, Colorado should be contacted.

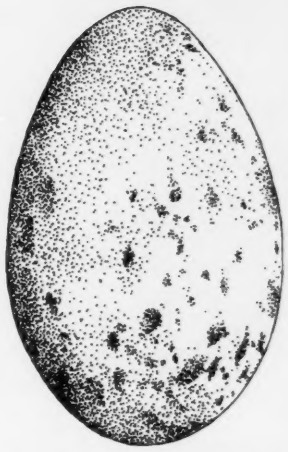


At reservoir projects investigated while preparing the *Handbook,* the adopted minimum instream flows ranged from 5 cubic feet-per-second (cfs) at Angostura Dam, South Dakota, to 5000 cfs at Hell's Canyon Dam on the Idaho-Oregon border. The reserved flow in Hell's Canyon was established primarily for navigation with nominal fishery protection. Seasonal flows were reserved for two-fifths of the cases reviewed. A short-term emergency flow sometimes is provided as evidenced by "Fish Flow '77" in the Columbia Basin. In 1977, state and Federal fish and wildlife agencies, Federal reservoir operating agencies, and private power companies coordinated their respective operation in response to a threat to the survival of juvenile salmonids migrating to the ocean. Temporary trade-offs were made possible without significant loss either to power companies or to reservoir operations.

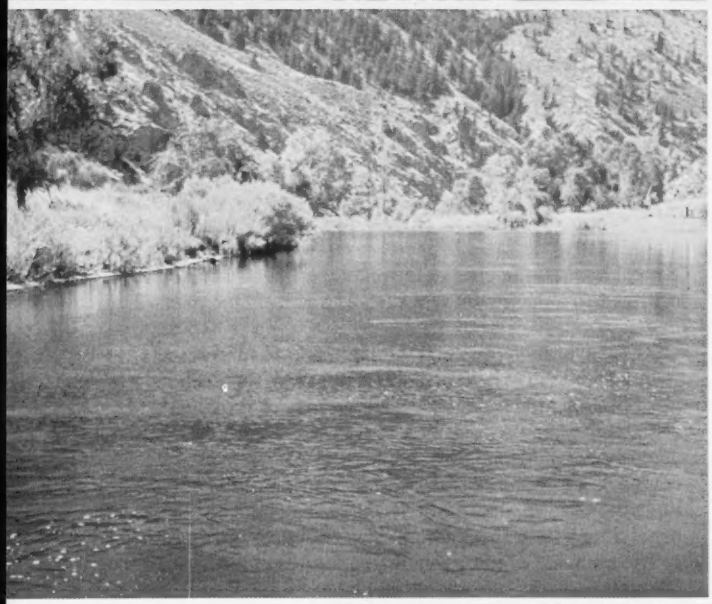
Western state water laws and administrative regulations frequently place severe limitations on water allocations for fish and wildlife. In many states, an instream flow for protection of fish and wildlife is not recognized as a beneficial water use. Therefore, water cannot be appropriated or reserved, or water rights purchased, for fish and wildlife instream needs. Even where such flows are recognized as a beneficial instream use, they still may be legally challenged. (See *Western Water Law,* in this issue.)

Another major constraint on reserving instream flows for fish and wildlife preservation is the resulting loss of reservoir storage capacity and yield for irrigation, power production, water supply, and other economic purposes. However, as demonstrated by "Fish Flow '77", a serious threat to a significant fish and wildlife resource can drastically alter reservoir operations, at least for short intervals. Still, in the absence of strong public pressure or obvious economic benefits from instream flow protection for fish and wildlife, economic development interests such as irrigation, hydroelectric, and water supply needs, have generally prevailed over recreation and preservation interests.

Sixty-two percent of the 44 cases where recommended instream flows were implemented to a high degree were judged to have been successful. Other case study investigations have reported that minimum instream flows generally have maintained fish and wildlife habitats, although population curtailments sometimes were significant. Good results in preserving habitats have depended on sound determination of instream flow needs and secure reservations which are honored by dam and reservoir operating agencies.



A nest at the edge of the South Fork of the Snake River below Palisades Dam, Idaho. The location ensures good visibility for the geese, but is very susceptible to flooding. The nest was, indeed, moved up the bank by the incubating goose to escape rising water.

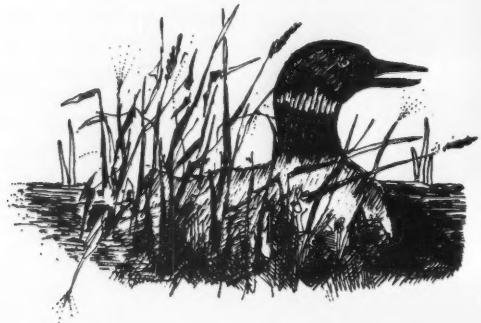


Instream flow in the Green River, Wyoming.

Costs for meeting minimum instream flow requirements are difficult to isolate since the specified flow quantities may partly or wholly meet other downstream project needs, such as furnishing water for irrigation, municipal use, and water quality management. However, the amounts of reservoir storage or stream diversions forfeited solely to ensure instream flows for fish and wildlife, multiplied by the market value of forfeited water use, represent a surrogate value for instream flow maintenance. An operations study of each dam and reservoir project could be conducted to calculate the quantity and value of flow forfeited solely for fish and wildlife purposes.

In some states, the direct purchase of appropriative water rights for fish and wildlife purposes is permissible. For example, a 1-cfs water right was purchased along Boulder Creek, Colorado, for $18,000 (1977 dollars). The cost of water rights will range widely depending on the location, prior use, and seniority of the right.

Two views of a Richmond-type deer escape in British Columbia, which provides a low-gradient ramp. Without this structure, animals would have little chance to exit the smooth, steep-sided walls of the canal.



Flow Fluctuation Control

Flow fluctuation control is requested primarily below hydroelectric power projects where power peaking operations can result in severe daily fluctuations in reservoir releases. Fluctuating flows may be evenly redistributed by reregulating dams and afterbays or through non-structural alternatives. Fluctuation control is intended to preserve fish habitats and populations and protect nesting waterfowl by moderating rates of change in reservoir discharge. Control of fluctuations also reduces direct destruction or damage to fish, benthos, and streambanks. Sudden significant changes in flows may strand fish and organisms important in the food chain; these changes are inimical to fish spawning and migration.

It has been reported that salmon fry, newly emerged from the gravel, tend to seek the quieter waters near the river banks. During periods of high flow, the river bars are submerged, but a sudden decrease in flow can expose the bars and strand the fry before they can swim to the deeper sections. Once stranded, they are susceptible to predators and exposure. In an opposite way, the nesting success of waterfowl such as Canada geese can be largely dependent on the magnitude, timing, and fluctuation of reservoir releases. Canada geese may nest on islands in a river channel or connecting lake. They prefer nesting sites on steep banks adjacent to the water at the upstream and downstream points of islands. If the geese nest while the water elevation is low during the early spring, a large increase in flows from spring floods or other causes will inundate the nesting sites.

Control of flow fluctuation was requested either in general terms or as a maximum change over a specific time period. For instance, limitations of changes in stream level to no more than 4 inches in 1 hour or 12 inches in 24 hours were requested and subsequently stipulated for Clearwater Dams No. 1 and 2 (Oregon). However, other requests for many projects failed to define fluctuation limits, using expressions such as "gradual changes", "fluctuations be kept to a minimum", or "regulated evacuation". Some of these general terms carried the implication of operations studies and quantitative refinement at a future date. It has been suggested that flow fluctuation control be requested on the basis of wetted perimeter. Where the water surface significantly decreases or increases in elevation within a critical habitat, the change in wetted perimeter should be confined to a maximum rate such as a percentage over 12 hours.

The major constraint on the magnitude of flow fluctuation control is the resulting loss of hydroelectric power production capacity during periods of peak demand. Also, flows cannot be constrained to the degree that flood control operations are affected adversely. Fluctuation control to protect waterfowl nesting areas also may be limited by the annual runoff predictions, which can affect negotiations for a schedule of reservoir releases.

The outcome of more than half (6) of the flow fluctuation control cases was judged to be successful; two applications proved unsuccessful even though they had been fully implemented. The populations below these two dams have been severely reduced because other habitat and

population improvement measures such as minimum instream flows were either rejected or incompletely implemented.

The opportunity cost for controlling flow fluctuation can be considered equivalent to the amount of peak power production foregone, multiplied by the difference between the price of peak-period power and the price of off-peak power. For the four applications of specific flow fluctuation controls, this cost could not be calculated because the quantity of peak power not generated due to flow control could not be determined. However, at Palisades Dam, where annual negotiations currently determine the flow levels and fluctuation limits contained in the release schedule, the annual lost hydroelectric power revenue has been approximately $11,500 (1977 dollars).

The maintenance of available drinking water supply is crucial to wildlife habitat planning.

Escape Ramps

The purpose of an *escape ramp* is to aid wildlife, mainly deer, in escaping from concrete-lined open canals. Ramps are considered an alternative to measures that prevent the entrance of wildlife into the canals such as closed conduits, canal covers, and fencing. Many different ramp materials and structures have been used in an effort to provide easy escape for wildlife. These have included reinforcing-bar mats and ladders, metal and wood cleats, snow fencing, metal airplane landing mats, and asphalt pads. These devices are attached to, or laid upon the canal banks, and assist the animals in climbing out of the canal. Sometimes a deflector is built into the channel to direct swimming or floating animals toward an escape ramp. The deflectors can be stationary, made of pipe or reinforcing bar, or they can be built from wood and float on the water surface.

Another type of escape ramp is discussed by Seaman in *Wild and Domestic Mammal Control in Concrete-Lined Canals* (1977). The basis of this design, which has taken several forms, is a recessed ramp with a low-gradient (3:1 or 4:1) slope, usually with some type of deflecting or repelling device to help direct animals toward the ramp. The initial design utilizing this approach was the Richmond deer escape built into the Okanagan Canal in British Columbia. A floating triangular boom deflects animals toward the low-gradient ramp. The ramp has grooves to roughen the surface so the animals can obtain a footing. Pacific Gas and Electric incorporated low-gradient deer escape ramps into their Tiger Creek Canal in California. To drive deer toward the ramps, however, they used aluminum strips hanging in the water, held by a cable. The moving water causes the strips to flash reflected sunlight, which repels the deer toward the escape ramp.

Another version of the Richmond deer escape is built on the outside of a bend in the canal. The eddy current developed by the abrupt widening in the canal tends to draw floating animals into the bay where the ramp is provided. The low gradient of the ramp, as well as the reduced flow velocities, allow the animal to climb out of the canal. To permit wildlife to exit the ramps but prohibit their entrance, one-way gates can be used. They were originally developed by the Colorado Division of Wildlife for use along highways.

If the escape device is placed on the original bank of the canal with a 1:1 or 1 1/2:1 slope, an animal will have a difficult time climbing out of the canal, particularly if it is exhausted from fighting the current. Also, algae tend to cover any submerged material, making the footing very slippery. Other considerations for design of escape ramps include construction costs, effectiveness at various flows, and the need for maintenance. One of the problems with inchannel deflectors, particularly the stationary type, is that they collect trash and algae. This can cause considerable hydraulic head loss and possibly overflows and structure collapse, making the deflectors very unpopular with maintenance crews and canal owners.

These applications of escape ramps were reviewed and judged to be marginally successful or unsuccessful. None of the ramps employed clearly demonstrated a reduction in wildlife losses. On the other hand, none of these ramps were the low-gradient Richmond type. Part of this failure is due to the difficulty of evaluating the effectiveness of these devices. Part is due to the inherent ineffectiveness of any design which does not reduce the normally steep slope of the canal. While cleats and asphalt ramps have been partially successful in some instances, Seaman feels that the Richmond-type ramp is superior and lists recommendations for its use and testing.

Costs for the Richmond ramps were unavailable as were the costs for the escape ramps used in the projects reviewed. Generally, the ramps should average $100 to $400 per unit (in 1977), depending on the material used. Construction costs for animal deflectors have been estimated at $2000 per structure in 1977. ■

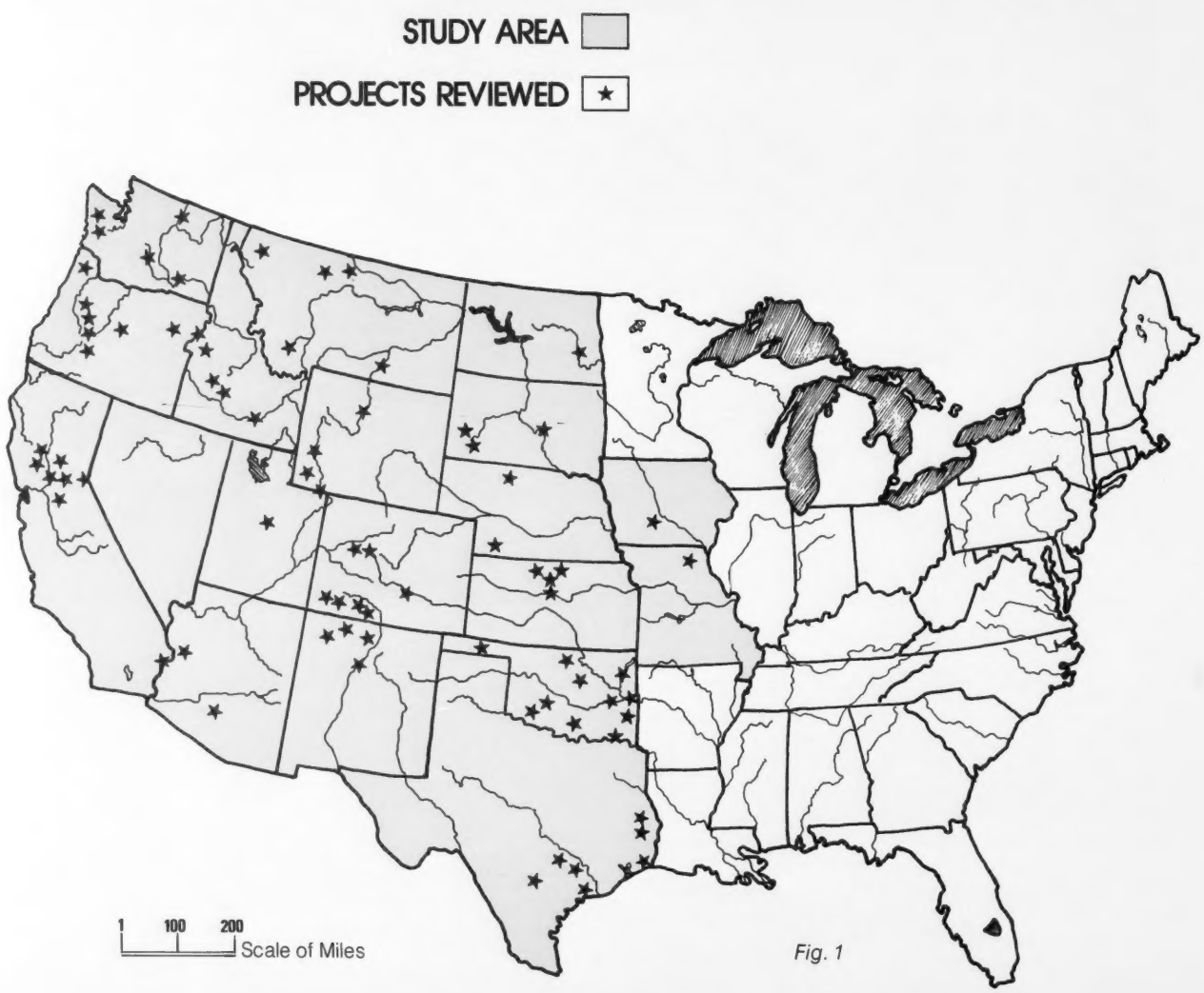


Fig. 1

The retrospective information provided by these five measure categories and the other 55 categories in the *Western Reservoir and Stream Habitat Improvements Handbook* will better enable planners to consider fish and wildlife in water development projects. This information will allow the formulation of sound alternative mitigation/compensation plans. The *Handbook* provides a guide for selecting more effective measures to recommend and negotiate among administrators, planners, biologists, and engineers of fish and game and construction agencies.

Habitat Improvement Measures

Reservoir Flood Basins
Selective clearing
Brush shelters
Tire shelters
Other fish shelters
Exposed area planting
Raised spillway

Reservoir Conservation Pools
Stage filling
Fluctuation control
Seasonal manipulation
Minimum pool
Aeration-destratification

Dam Discharge Systems
Low-level intakes
Multi-level intakes
Spillway deflectors
Stilling basin

Streamflows, Riffles, & Pools
Minimum flows
Fluctuation control
Reregulating dam
Maximum flows
Current deflectors
Check dams
Other instream devices
Artificial meanders
Isolated oxbows

Streamside Protection
Bank cover
Bank stabilization
Snag clearing

General Practices
Food-cover planting
Browseway clearing
Grazing control
Fish-waterfowl ponds
Wetland dredging-diking
Macrophyte-algae control
Settling-retention basins
Land acquisition
Reservoir, flood plain zoning

Population Improvement Measures

Fish Propagation
Hatcheries
Artificial spawning channel
Spawning riffles
Spawning bed-marsh
Nursery-rearing ponds
Nursery cove barriers

Fish Passage
Trap-haul facilities
Fishways
Conduits-culverts
Turbine bypass

Fish Stocking & Control
Fish stocking
Fish screens
Barrier dam
Other control devices
Fish eradication

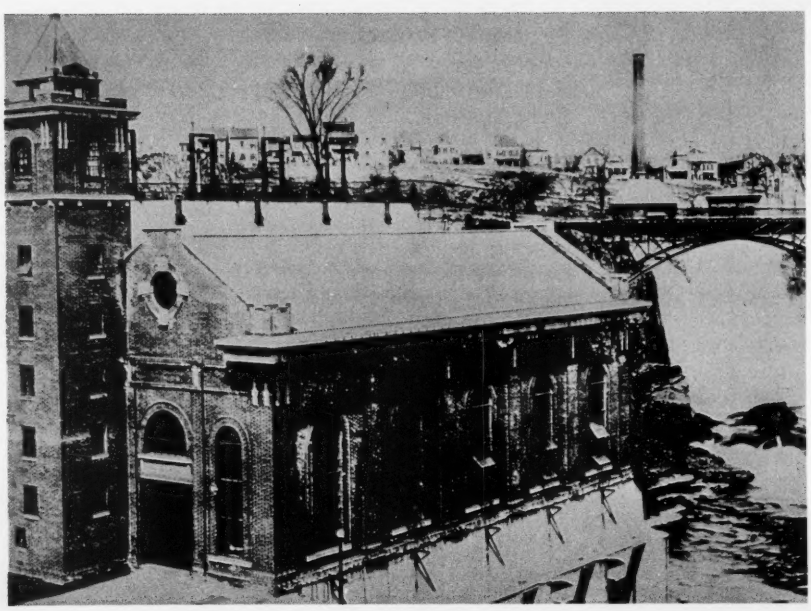
Wildlife Propagation & Control
Nesting structures
Nesting islands
Wildlife fencing
Watering ponds-guzzlers

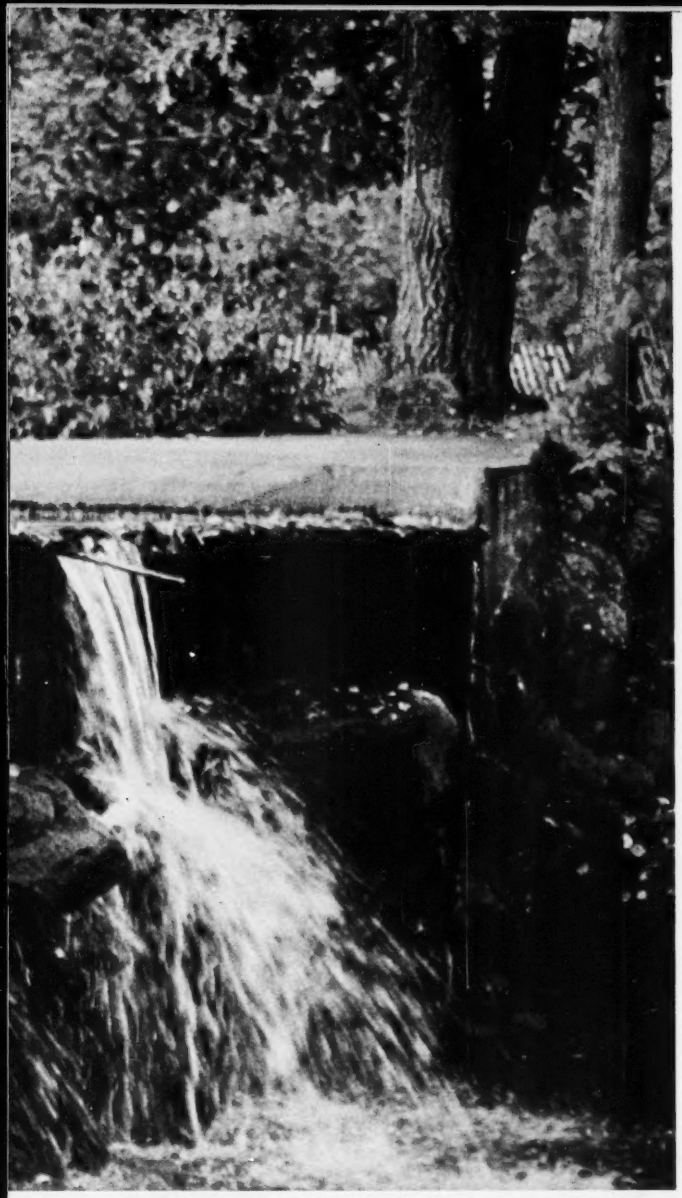
Wildlife Protection At Canals
Conduits-Canal covers
Wildlife fencing
Wildlife crossings
Escape ramps
Other protection

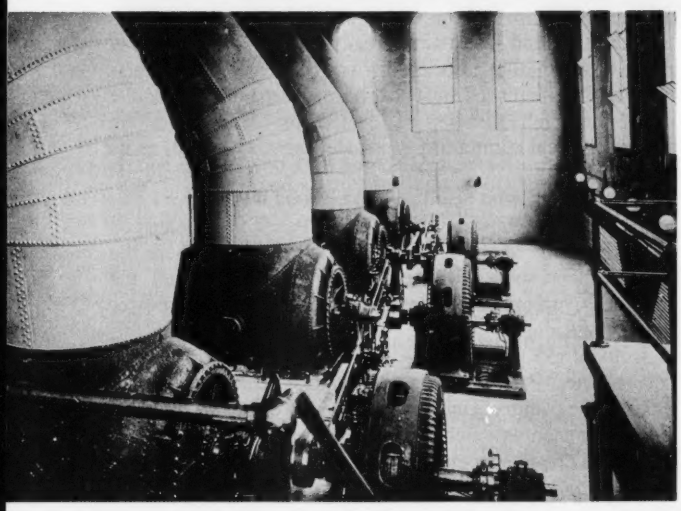
Classification scheme for the Western Reservoir and Stream Habitat Improvements Handbook.

Constructed in 1914, the hydroelectric generating facility on the Great Falls of the Passaic River in Paterson, New Jersey, had a total production capacity of just over 4900 kilowatts.

Four S. Morgan Smith double-runner Francis turbines were driven by the 65-foot fall of the Passaic at Great Falls.







LOOK BACK AT THE FUTURE

by **Norman L. Clapp and Albert H. Garner**

Water power—the energy source that powered the early industrial development of America—is back in the news again. This time it is the undeveloped hydroelectric potential of existing dams. Some of these dams are large but not utilized to their full capacity, some of them have no hydroelectric generation facilities installed, and a great many of them are small, low-head structures once used, but long since abandoned as power sources when the electric utility industry moved on to the greater attractions of larger scale generation.

But thousands of dams that once turned the wheels of the textile industry in New England, ran sawmills, ground corn and wheat into meal and flour, supplied power for early factories in the east, the south, the midwest, and elsewhere are still there in varying states of disuse and neglect.

In 1900 almost 20,000 manufacturing establishments in the nine northeastern states depended primarily on water power. In Maine, New Hampshire, and Vermont, hydropower remained the principal source of energy for industry, and it met between a quarter and third of industrial power demands in Massachusetts, Connecticut, and New York.

The world's first hydroelectric central generating station built was completed in 1882. Located on the Fox River in Appleton, Wisconsin, the plant provided enough capacity to power only 250 lightbulbs! But its impact on the future was much larger. Rivers and streams all over the country were rapidly developed to generate electricity. Although the early hydroelectric plants were small, they soon prompted the development of larger installations.

Mr. Clapp and Mr. Garner are commercial energy consultants based in Washington, D.C. Mr. Clapp is a former Administrator of the Rural Electrification Administration.

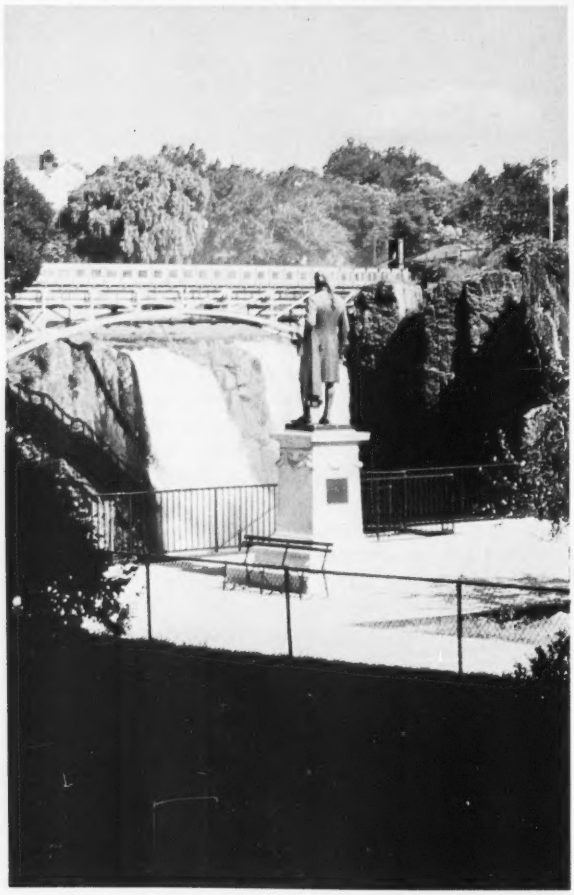
World War I saw the development of Muscle Shoals, Alabama to generate the electricity needed to produce nitrogen for munitions. Out of the post-war debate over the peacetime use of Muscle Shoals came the concept of the Tennessee Valley Authority (TVA) to harness the rest of the energy of the Tennessee River and its tributaries, prevent floods, improve navigation, and turn it all toward the improvement of life for an entire region.

Flood control and production of electricity joined hands in other areas, principally the southeastern states and parts of the southwest. Reclamation of arid lands through the impoundment of waters for irrigation also added substantially to the hydroelectric resources of the nation.

TVA, the Department of Energy, and the Power Authority of the State of New York—with power from Niagara Falls and the St. Lawrence River—are today major marketers of hydroelectric power. Altogether, hydroelectric developments provided almost 69 million kilowatts of power in 1977 and generated over 220 billion kilowatt hours.

But as the hydroelectric potential was being developed on a larger and larger scale from big dams and major impoundments of water, the smaller sites were being abandoned as power stations by electric utilities. The economies of scale and low fuel costs dictated the nation's energy development, and the smaller stations were allowed to fall into a state of disrepair. The expense required to rehabilitate these plants usually could not be justified because of the lower per-unit costs of large-scale competitive energy sources.

Alexander Hamilton, the first Secretary of the Treasury, recognized the industrial power potential of the Great Falls cataract as early as 1791. (Photo by Joel Weissman.)



Two significant developments now promise to change all that. First is the critical increase in the cost of constructing large-scale generating capacity of all kinds. Second is the enormous increase in the cost of oil as a fuel for intermediate or peak-load generation that has resulted from our growing dependence upon imported fuel oil and the prices set by the oil exporting countries following the oil embargo of 1973. Base-load coal-fired plants which came on line in 1974 were built at a cost of approximately $220 per kilowatt of capacity. Nuclear plants of the same period cost around $370 per kilowatt of capacity. One study estimates that coal-fired plants coming on line between 1987 and 1989 will be as high as $1150 per kilowatt with corresponding nuclear plant costs approaching $1270 per kilowatt. Indications are that inflation and unexpected delays may prove these estimates low, with some plants costing as much as $2000 per kilowatt. Fuel oil for utility boilers, which cost an average .65¢ per kilowatt-hour in 1972, averaged 2.34 cents per kilowatt-hour in 1977. The plans of the OPEC countries to increase the price of crude oil by 14.5% this year will drive utility fuel bills even higher.

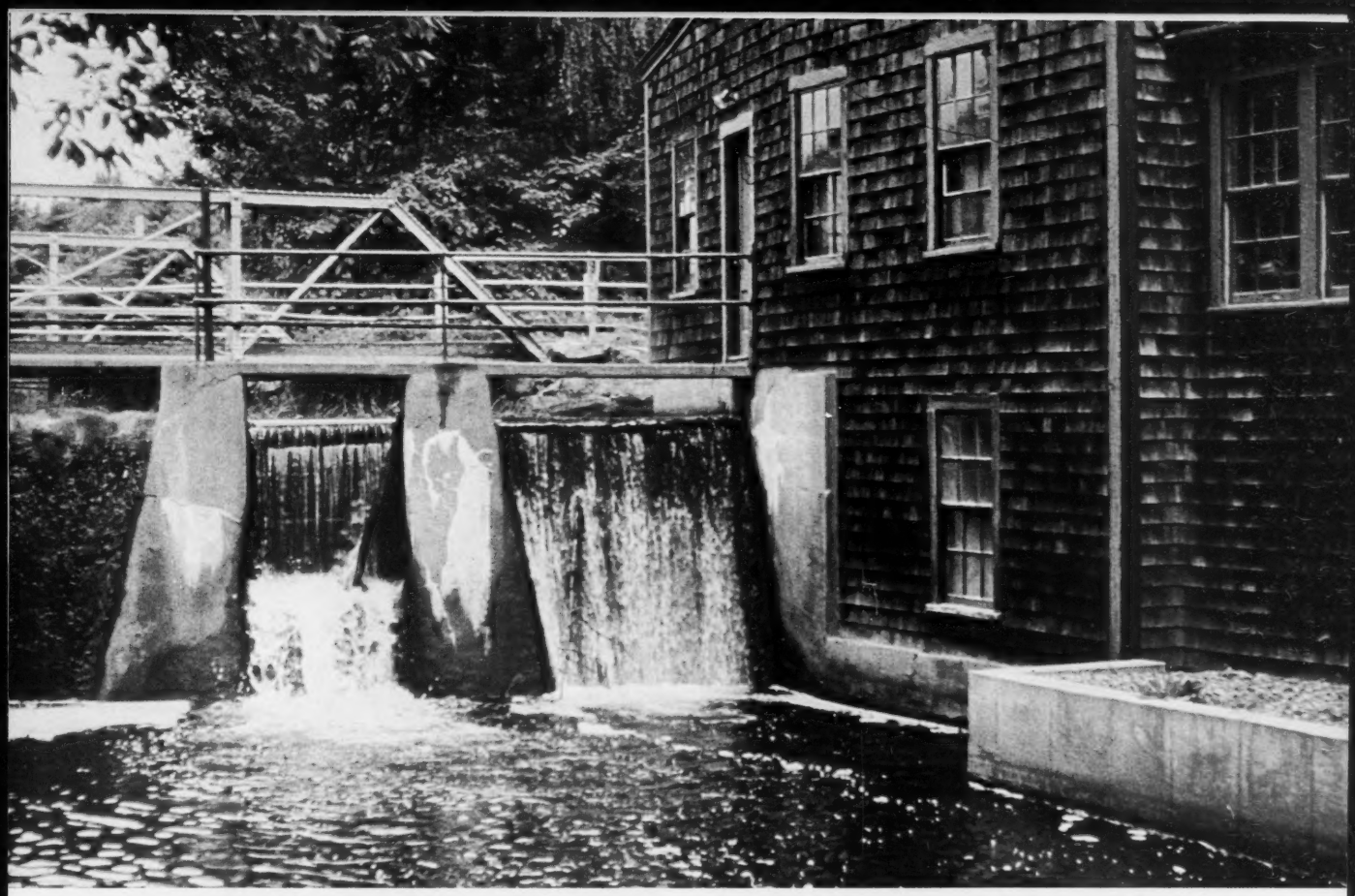
This has prompted a new look at a number of hitherto ignored alternatives, including all those old dams that were put on the sidelines over the past 30 years or more.

Perhaps no single public figure has been more responsible for the reexamination of the small hydro potential than David Lilienthal, a founding director and subsequent chairman of TVA and a builder of big dams not only in the Tennessee Valley but, in later years, overseas as well. As he saw the mounting difficulties of other sources of electrical energy gather momentum, he was among the first to speak out and urge a reappraisal of the possibilities of bringing the smaller, long neglected hydroelectric sites back into the mainstream of the nation's energy supply.

He pointed to the great number of existing, but unused, small dams located throughout the country, the comparative absence of environmental problems in making use of dams already built and reservoirs already in place, and the new range of alternative costs against which the economic feasibility of the small sites must now be measured. He also spoke of what the rehabilitation of local dams could do for the revival of local community spirit and morale, as well as its economy.

Among those who heard and understood was Mayor Lawrence Kramer of Paterson, New Jersey. Paterson is located on the Great Falls of the Passaic River, and there, where the river cascades some 65 feet over a spectacular waterfall, the penstocks, turbines and generators of a once-operating power plant stand idle.

A city of 155,000 people in an incorporated area of only 36 square miles, Paterson is one of the most densely populated cities of the country. Under the leadership of Mayor Kramer, it has launched an extensive program of community development to create new employment opportunities and restore the pride and spirit of a community beset with more than its



Typical small hydropower site in Kingston, Massachusetts. (Photos of representative Mass. sites courtesy of New England Division, CofE)

share of industrial decay and unemployment so common among older urban centers.

An important part of this program is to be the restoration of the hydroelectric plant at Great Falls. A feasibility study has been completed, and an application for a license from the Federal Energy Regulatory Commission is being completed.

The Paterson Great Falls project represents a most unique mix of early history and present day energy realities. The history goes back to Alexander Hamilton, this country's first Secretary of the Treasury. It was Hamilton who sounded a call for the development of industry in the United States as an escape from the exploitation of British mercantilism. And it was Hamilton who took the lead in organizing the Society for establishing Useful Manufactures (S.U.M.) at Paterson as the first corporation in the state. It was chartered by the Legislature on November 22, 1791.

During his search for a proper location for S.U.M., Hamilton received a letter from an associate describing the falls of the Passaic. It was stated that "one of the finest situations in the world . . . can be found there . . . the quality of the water is good and in sufficient quantity to supply works of almost any extent." Acting on this and other advice, the area surrounding Great Falls was chosen in 1792 to be the home for S.U.M. It was named Paterson after the then governor of New Jersey.

After a shaky start during which it came close to collapse, S.U.M. grew and prospered. By the early 1800s, three raceways, or canals, conveying water to power industry had been built. In 1815, half of the manufacturing concerns in the state were located in Paterson. By 1882, water flowing through S.U.M.'s raceways provided 2108 horsepower for local industry.

With the advent of the 20th century, the energy needs of Paterson's industry exceeded the capacity of the raceways. Also, the technology of hydroelectric generation had become established and offered significant advantages over the traditional water wheel mechanical power. Therefore, in 1912, S.U.M. began construction of a hydroelectric generating station at Great Falls. The plant, which was completed in 1914, was equipped with four S. Morgan Smith double-runner Francis turbines with a total installed capacity of just over 4900 kilowatts. Eventually S.U.M. constructed a steam plant to supplement the hydroelectricity produced at Great Falls. Surplus power was sold to the Public Service Electric and Gas Company (PSE&G), the electric utility serving Paterson.

A century and a half of industrial history ended in 1945 with the sale of the assets and entitlements of S.U.M. to the City of Paterson for $450,000. The city then leased the Great Falls hydroplant to PSE&G, which operated the plant until 1969, when it was determined that extensive repair would be needed in order to continue the plant's operation. In view of the lower costs of large central-station generation, it was decided that the required expense could not be justified. The plant ceased operation.

Then, in 1971, the old industrial area, including the dam and powerplant complex, the raceways, and many of the

early factory buildings, was declared a National Historic Landmark. This area constitutes what is called the S.U.M. Historical District, and a grant of $11.3 million from the Economic Development Administration has recently been obtained for its development. Plans call for the rehabilitation of about 60 historic industrial structures for mixed use, and the redevelopment of the river front.

It is in this climate of historical awareness and activity that the efforts to restore the hydroplant are taking place in Paterson. As Mayor Kramer has put it, "By restoring and reactivating existing hydropower sites, we will be preserving much of the heritage upon which our society is based."

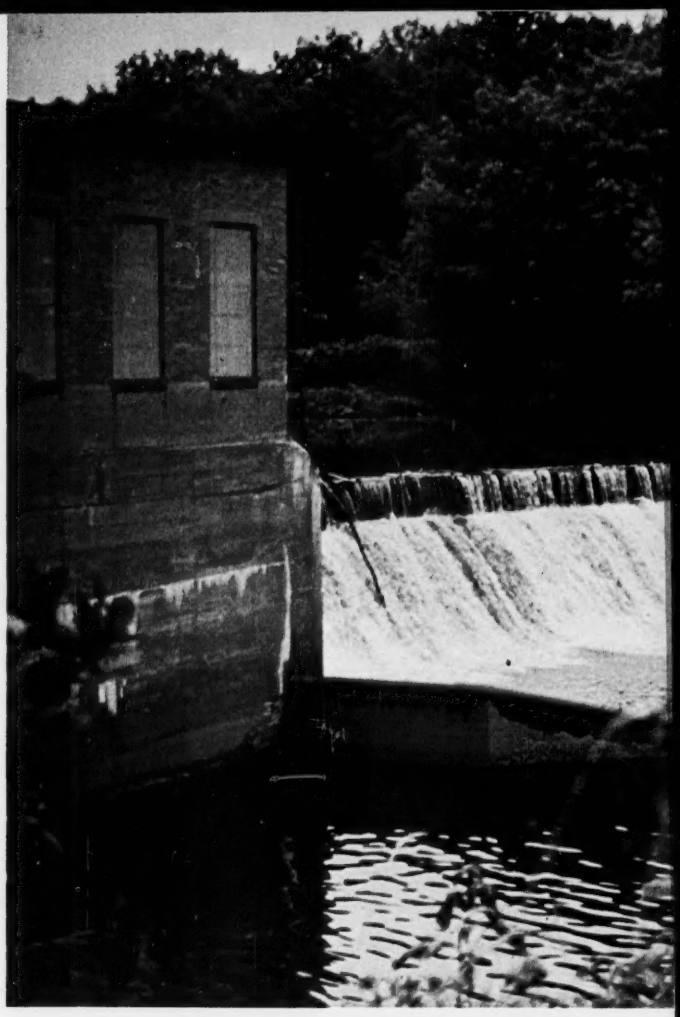
But these efforts are not based solely on historical considerations. As a result of the dramatic increases in fuel costs, which by all accounts will continue to rise, the economic soundness of restoring generation at many abandoned sites is assured.

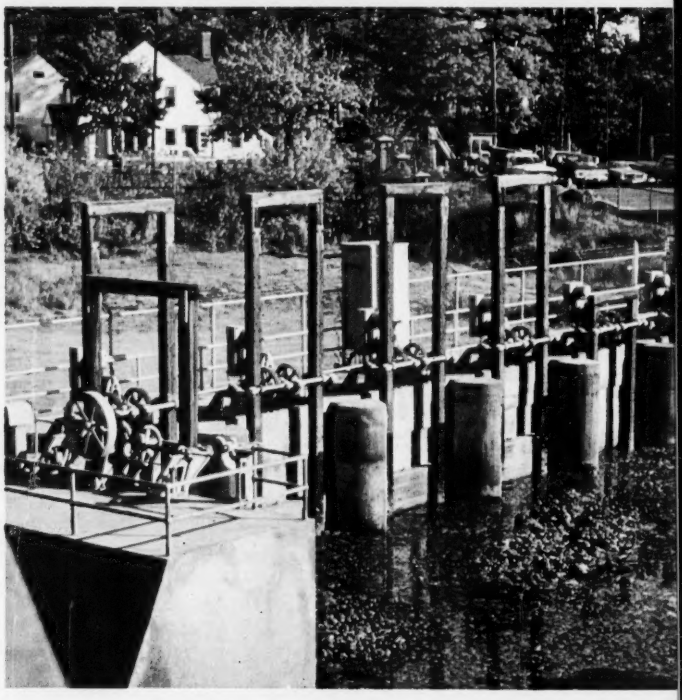
A feasibility study which examined a total of 17 development alternatives for the Paterson project was completed last fall. Consideration was given to rehabilitation and updating of the existing units, installation of various types and capacities of new turbines, repairing the existing dam, and construction of a new dam. The options for the new turbines included fixed and adjustable blade tube type, and cross flow designs, both of which are considered applicable to the 65-foot head and the flow conditions at Great Falls. The range of installed capacity examined was between 4600 and 10,500 kilowatts.

The capital costs of the alternatives, including site rehabilitation, fell between $717 and $1131 per kilowatt. The unit cost of service, including capital, operation and maintenance, project administration, and other annual costs, is projected to vary between a low of 2.10 cents to a high of 2.58 cents per kilowatt-hour in 1981, the first year of proposed operation.

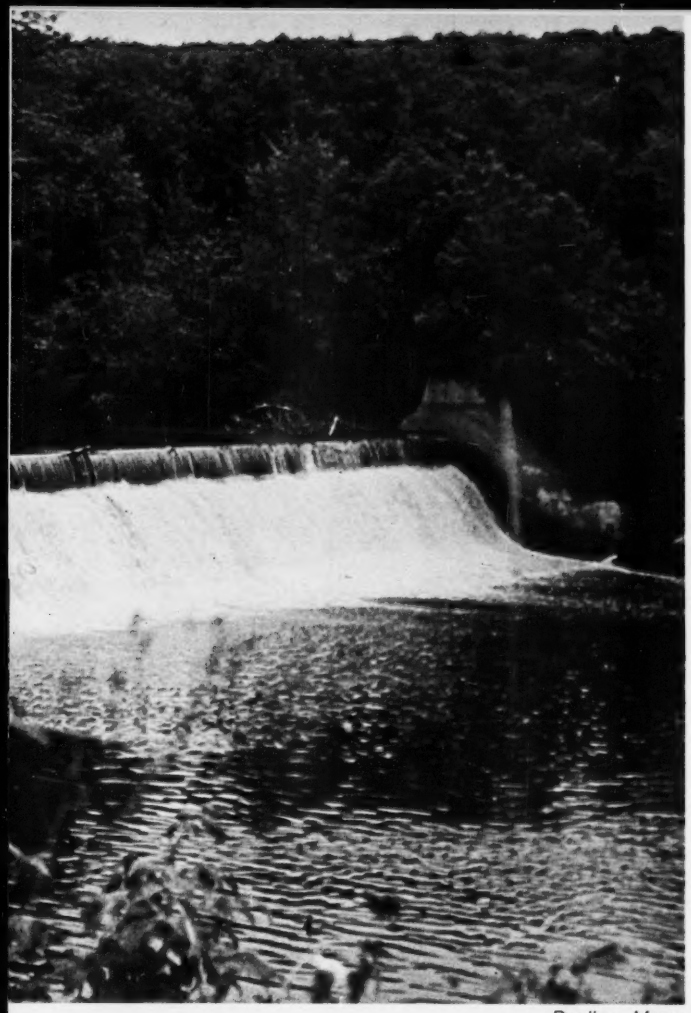
The local utility has indicated a willingness to purchase all of the energy produced at the restored power plant. Although a purchase price has not been negotiated, a conservative 1977 value for hydroelectricity in the Paterson area was established to be 2.5 cents per kilowatt-hour. This was based on a number of considerations, the most important of which was competitive fuel costs. Due to the wide seasonal variations in the flow of the Passaic, little or no firm capacity can be developed, and therefore no value was assigned to this aspect.

Adjusting the above value by a modest annual six percent increase in competitive energy costs, the value expected during the first year of operation is 2.98 cents per kilowatt-hour. Comparison of this to the costs of production indicates that for every alternative, revenues will exceed costs. The development of the alternative of uprating the existing units to a total capacity of 7500 kilowatts would generate over $270,000 in net revenues for the city during the plant's first year of operation, on the basis of an average annual flow. Since much of the cost associated with the plant's operation is fixed capital expense, these net revenues will tend to rise further during the project's life as competitive fuel costs increase and the value of the energy increases.





Hydropower facility in Ludlow, Mass.



. . . Dudley, Mass.

So the project itself makes sound economic sense. But, as the Mayor has stated, "The energy produced from the hydroelectric facility is not viewed as an end in itself, but as a vehicle to be used to sustain and promote the economic health and vitality of our city."

Nearly two hundred years ago, Alexander Hamilton explained his reasons for creating the Society for establishing Useful Manufactures in much the same way.

Although the history of the Paterson project is unique, the economics of its feasibility do not appear to be unusual. On the basis of both study and some experience to date, capital costs for rehabilitation or installation of hydroelectric facilities in existing small dams can be expected to fall in the $1000 to $2000 range per kilowatt of capacity, with the cost of energy produced ranging between 2.4 and 5 cents per kilowatt hour. With the cost of fuel oil already approaching 2.5 cents per kilowatt hour produced and promising to go higher, the feasibility of such projects, although marginal at the moment, seems assured in the future.

In any event the U.S. Department of Energy, under the recent authorizations of the Congress, is seeking to find out. More than 50 sites, distributed broadly across the country, are now being studied to determine the feasibility of hydroelectric installations in existing dams with heads of 20 meters or less. These were funded out of an allocation of $2.5 million in Fiscal Year 1978. For the present fiscal year, the Congress has appropriated $10 million for 90 percent loans to finance more studies, perhaps 200 or more, at additional sites of existing small dams. Any of these study loans may be forgiven by the Secretary of Energy if the studies show to his satisfaction that project development is not economically or technically feasible.

Demonstration projects are coming. The upgrading of the damaged hydroelectric plant at Idaho Falls, Idaho is the first. Others for which proposals were solicited by the Department of Energy last fall are in the works. The demonstrations are to show not the technology, but rather the economic viability of such projects and the marketability of the power from such smaller installations under current operational and marketing requirements. They probably will demonstrate some of the institutional problems encountered in developments of this size, also. All this will be useful in learning how to take advantage of this unused energy potential most effectively.

And the potential is there. It is not of sufficient magnitude to offer an overall solution to the nation's energy problems, but it is significant. With relatively short lead times for construction, it can buy valuable time for the electric industry and the nation's productive economy, while the major solutions in fossil-fired and nuclear-fueled generation are developed and delays overcome.

In 1977, at President Carter's direction, the U.S. Army Corps of Engineers undertook to determine just how much additional electric generating capacity could be added in existing dams in the nation. The Corps' study, entitled *Estimate of National Hydroelectric Potential at Existing Dams*, was the first thorough examination of its kind. The Corps concluded that there is as much as 54,600 megawatts of undeveloped capacity at existing structures which, if developed, would generate 160 billion kilowatt-hours of electricity. This is broken down into three categories:

- As much as 5100 megawatts could be added to present hydro capacity by replacing present turbines and generators with newer, more efficient equipment.
- An additional 15,900 megawatts could be obtained by installing additional turbines and generators at existing hydropower sites.
- A potential of 33,600 megawatts could be realized by constructing powerhouses at existing dams which are not presently or have never been tapped for the production of hydropower.

The latter category includes some 26,600 megawatts at sites with an individual potential capacity of less than 5 megawatts. These small sites could generate more than 84 billion kilowatt-hours annually. It must be noted, of course, that the number in each category represents an upper limit on the physical potential; environmental, economic, and social factors were not considered in the study.

The public interest in this potential is manifested too. From the days of 1976 when David Lilienthal attracted national attention for his insistence on a new look at renewed hydroelectric production from the nation's neglected small dams, public interest has steadily mounted. Turbine manufacturers, engineering firms, and the Federal government can attest to that in the number of inquiries received. Making better use of what we already have is a type of conservation that appeals to people.

. . . Groton, Dunstable, Tynsboro, Mass.

The Congress early sensed the gathering momentum behind the small hydro idea and authorized several programs of the Department of Energy. Although the Administration budget did not provide for a low-head hydroelectric demonstration program, the House of Representatives Committee on Science and Technology and the Senate Committee on Energy and Natural Resources recommended that $15 million be authorized "for the initiation of a broad program to exploit the potential of low-head hydroelectric power resources." In response to this recommendation the Congress did appropriate $7.5 million, which, with other funds available from Department of Energy allocations, made a $10 million program possible in Fiscal Year 1978—of which $2.5 million was used to fund feasibility studies. The balance was dedicated to technological research and development and an initial demonstration program.

In the present fiscal year the funding for small hydroelectric development has been increased to a total of $28 million. Of this, $10 million is intended for feasibility studies and the balance for research, development, and demonstration.

Low-head hydro is now one of the energy technologies officially designated by the Department of Energy for commercial application.

And finally, although the implementing appropriations are still far short of the mark, Congress has authorized a low-interest loan program of $100 million annually for three years to provide up to 75 percent of the project costs for hydroelectric development at sites of not more than 15,000 kilowatts capacity in existing dams. Although the President's proposed budget for the coming fiscal year does not recommend any significant funding for the project loan program, Congress may yet again take the lead in funding the program on its own initiative.

The potential energy is there to be developed, the economic feasibility for a great deal of it appears to be assured, the public interest is mounting, and there only remains to be supplied the necessary funding and leadership to bring it all together. But what Paterson, New Jersey and some other pioneers in this field are already doing, can be done in hundreds if not thousands of locations across the country. ■

Some 1500 tiny power stations along small streams which once provided energy for saw mills, flour mills, and forges may soon add more than two billion kilowatt hours annually to Sweden's energy resources. Sweden has for some time refused to build any more large hydroelectric dams because of their effect on the environment; however, the conversion of the small dams will have no similar damaging environmental impact. Priority for rebuilding will go to plants with a generating capacity of at least 100 kilowatts. One factor making the old hydro facilities uneconomical was that they required constant supervision if a proper water flow was to be maintained. Today, however, new techniques, including an automatic turbine, make an attendant unnecessary. *(World Environmental Report)*

MUNICIPAL WATER DEMAND MANAGEMENT

By **A. P. Grima**

A safe water supply for urban North America developed under the twin pressures of providing business districts with fire protection and households with non-contaminated drinking water to reduce the chance of epidemics from cholera, typhoid and dysentery. So, at first, municipal water was to some extent a "social" good: it helped to prevent devastating fires and it contributed to public health. The level of municipal water use has been rising both as a result of urban growth and as a result of per capita increases in use. Urban water has now become an "economic" good: it is a commodity whose level of use is a matter of how much users are willing to pay for it and for the cost of supplying it.

Even where water resources are relatively plentiful, developing a safe, potable water supply is increasingly expensive. It has been esti-

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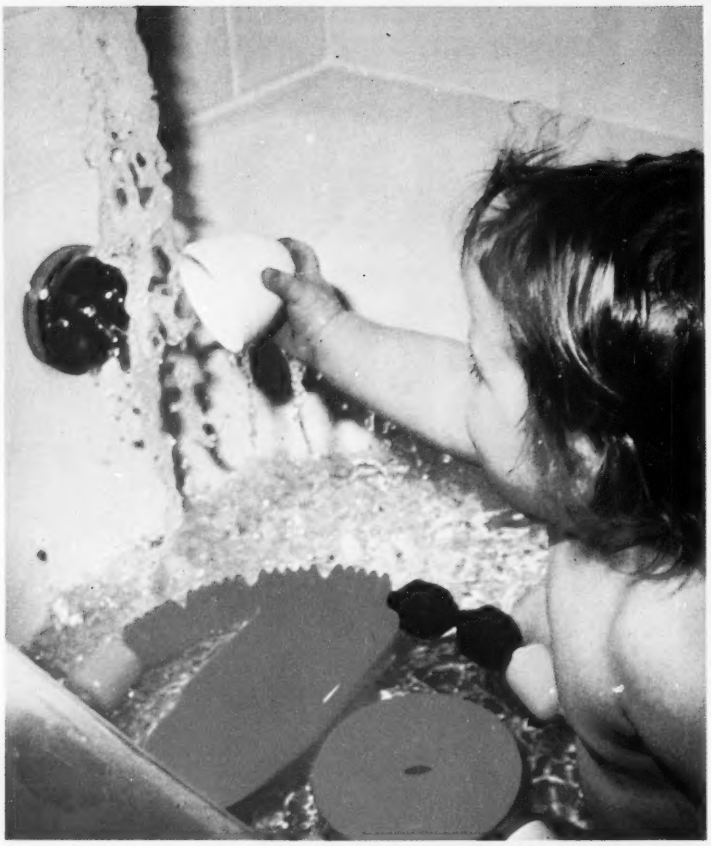


"The cheapest and easiest way to encourage water conservation is by making consumers realize how easy it is to save on water use."

mated that investment in water utilities in the U.S. in the late 1960s was greater than the combined investment in iron and steel and more than twice the investment in gas utilities.

The total investment requirements for urban water supply systems are increasing due to a backlog of deficiencies and rapid urban growth in all parts of the world. Investment requirements per capita and investment costs per unit of water produced may also be expected to increase due to higher per capita consumption, more marked peaks in demand, the need to develop less accessible sources of supply as the present sources prove inadequate to meet increasing demands, and the tendency for urban sprawl. Public expenditures are a hot political issue; municipal finances are under pressure from competing services such as education, solid waste disposal and mass transit. Therefore it is opportune to investigate whether investment costs for residential water supply could be reduced by conservation approaches, how and by how much.

Apart from cost considerations, efficient use of municipal water merits attention because of the increasing demand and pressure upon the water resource in the form of withdrawals for industrial, domestic, irrigation and other uses and in the form of assimilating waste from industry, towns, agriculture and other sources of emission. Water conservation also saves resources in other sectors, e.g. it costs twice as much to provide secondary treatment for waste water as to provide potable water. In addition, municipal water supply has been a municipal enterprise, which acts as a regulated monopoly. Are these regulated monopolies pricing their output rationally?

Alternative Choices

A municipality faced with a potential water shortage has the option to accept the shortage and institute some form of water rationing. In the past, municipal water managers have opted to increase the water supply by constructing reservoirs and extra storage facilities, expanding treatment capacity, developing new groundwater supplies and diverting surface water. In extreme cases the supply could be increased by desalination or renovating waste water. The fiscal, environmental and political costs of increasing the municipal water supply are becoming clear and have led researchers and managers to investigate alternatives which attempt to make better use of existing water supplies within the municipality.

This article will focus on two alternatives: metering and the design of more rational water rates. The literature on metering and pricing is extensive and the results of research are clear: metering and pricing achieve substantial reductions in municipal water use in general and residential water use in particular. Unfortunately, most municipalities in North America and Western Europe have not adopted metering and pricing policies that would encourage the conservation of expensively produced piped water. For example, several of the largest cities in North America have a low proportion of metered residential water use (e.g. Denver, Toronto, New York and Hamilton); practically all municipalities in Ontario with a population of 18,000 or over have a declining block rate.

In addition to metering and pricing there are many other variables that influence the level of water use per dwelling unit. In order to put the discussion into a wider perspective it would be helpful to inquire into the nature of systematic variations in residential water demand and examine the empirical evidence.

Factors Affecting Municipal Water Use

One may reasonably hypothesize that residential water use in a particular city depends on a set of observable environmental conditions. Some of the factors or conditions relate to supply and others reflect socio-economic conditions. Some

factors relate to the quality of service, e.g. taste, pressure, purity, dependability. Other factors (e.g. metering and price) are available as management tools without any reduction in the level of service. The inclusion of such factors would result in better projections of water than the present rules of thumb based on extrapolation of past trends and upon best judgements as to probable future requirements.

Public Information

One set of factors affecting residential water use that may be used by management to affect the level of demand includes exhortation and education of consumers, control of leakage and the allocation of water of different quality to different uses. The impact of exhortation and regulation alone, in an emergency, was shown by a reduction in water use by 25 percent in New York City during the 1965 water shortage.

The cheapest and easiest way to encourage water conservation is by making consumers realize how easy it is to save on water use (or how easy it is to waste water). A household faucet runs 3-5 gallons of water a minute. So it makes sense to turn off the tap while shaving or brushing one's teeth. Most flush toilets use 4-8 gallons per flush and this is the highest water use in homes. An average automatic washing machine uses 50 gallons of water per load; so wait until you have a full load. Low-flow shower heads also help to conserve water. A dramatic example of the effects of education on conservation is reported in a special 1978 issue of the *Great Lakes Communicator* devoted to water conservation: "In Elmhurst, Illinois a $55,000 conservation effort saved $400,000 the city would have needed to sink a new deep well".

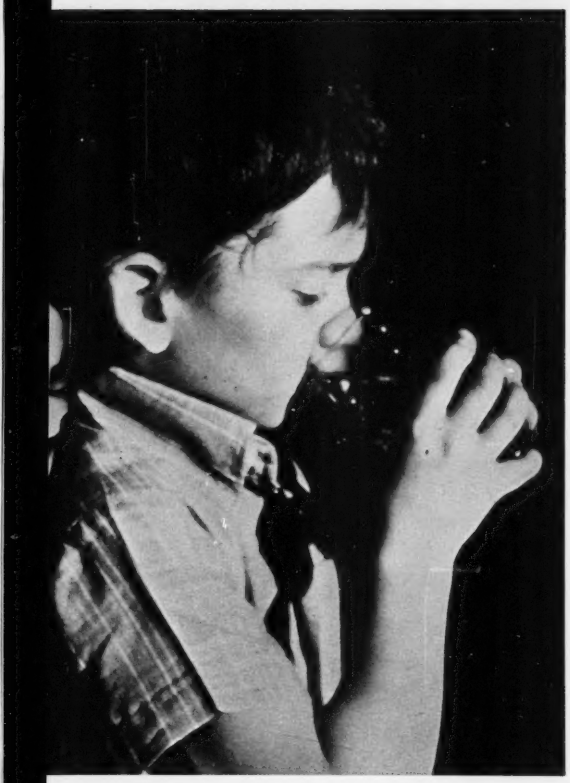
The efficacy of education and exhortation reinforces the argument that as long as consumers are made aware of ways to conserve, they will respond, particularly if it saves them money.

In a 1966 study of water resource management by the Northeastern Illinois Planning Commission it was reported that a 50 percent reduction in underground leakage would reduce the public water supply use by 115 million gallons daily (i.e. about 10 percent of total use in 1961). By comparison, the conversion to smaller toilet flush tanks would reduce use by 50 mgd while the elimination of over-irrigation of lawns would reduce water use by 12 mgd.

Socio-economic factors

Another set of variables affecting residential water demand refers to the household characteristics, e.g. type of housing, size of household, income level, the type of neighborhood effluent

"Urban water supply systems developed as households demanded disease-free drinking water . . . and business districts fire protection."



disposal (sewerage connection vs. septic tank) and consumer preferences (e.g. gardening). Apartment dwellers may be expected to use less water, partly because of smaller average household size, but mainly because of lower needs for lawn sprinkling. Households with septic tanks are reported to use slightly less water than comparable households with sewage connections, whereas the highest water users are households on a flat rate (i.e. not metered).

Family income, as expected, influences the level of water use. One would not normally attempt to influence these socio-economic characteristics. However, it is essential to include variables that reflect household characteristics in order to improve the forecasting of demand for water and in order to make allowance for increases in the standard of living and for demographic changes (e.g. more new families seeking single-dwelling units).

Climatic Conditions

A 1958 study of 44 American cities found a significant inverse relationship between residential water use/person in 1955 and the number of days of rainfall in July through August 1955. As expected, the regression coefficients for the 21 large cities and the 23 small cities are different, since larger cities have a lower per capita sprinkling use due to a higher proportion of families living in apartment blocks. In the U.S. the average sprinkling use is much lower in the east than in the west, generally reflecting the more humid conditions. However, sprinkling use on the maximum day (i.e. the critical variable in designing water supply systems) in the

". . . It costs twice as much to provide secondary treatment for waste water as to provide potable water."

east was almost equal to that in the west (i.e. the waterworks in the east have unused capacity more often). In non-metered areas (all in the west) reported lawn sprinkling on an annual basis is nearly three times the replenishment requirement; on a summer basis the ratio is 2½ and, even on the critically important maximum day, the ratio is 1.66. By comparison, in metered areas in the west, the ratio is about 0.6.

Metering

Metering is probably the most important variable affecting water supply that may be used as a management tool. There is a considerable controversy about the impact of metering, due to a confusion between metering and marginal pricing. Unless metering is accompanied by a suitable consumption charge, then metering *per se* need have no effect on water use except for a transitory impact. (The introduction of metering at St. Catharine's, Ontario, did not significantly affect water use.[1]) With this limitation one may point to various studies which show that metering tends to reduce sprinkling use and other uses on the critical maximum day and peak hour.

Table 1 demonstrates that in-house uses have a very high priority and metering does not affect such high priority water uses as washing, cooking, and bathroom use. The impact of metering (*and* the price attached to water use) on sprinkling, however, deserves to be noted for two reasons. First, sprinkling is a lower priority use than in-house use and consumers are willing to conserve if they are given any incentive. Second, sprinkling may be expected to be heaviest on the maximum day use which is the demand that municipalities aim to meet; therefore the reduction in sprinkling use may be expected to lower the design demand for the system and reduce costs.

[1]J. R. Pitblado, *The Effects of Metering on the Domestic Consumption of Water:* The City of St. Catharine's (Ontario). B.A. thesis, Department of Geography, University of Toronto.

Automatic washing machines are notorious water consumers. Use them only when fully loaded.

*Table 1. Metered and Unmetered Residential Water Use, West United States**

	Metered & Public Sewers (10 areas)	Flat Rate & Public Sewers (8 areas)
	(gallons per day per dwelling unit)	
Domestic Use		
Mean annual use	247	236
Mean of Maximum day uses	454	431
Mean of peak hour uses	1,214	1,016
Sprinkling Use		
Mean annual use	186	420
Mean of maximum day uses	707	2,083
Mean of peak hour uses	2,076	4,812

**Source: Linaweaver, F. P., Jr.; Geyer, J. C.; and Wolff, J. B., (1967)*

Industry using a lot of water tends to locate in cities where water costs are low.

The average maximum day use of non-metered consumers is three times the use for metered consumers. Management efforts to reduce these peak uses would have a particularly salutary effect on costs since some of the storage capacity is used on only a few dry and hot days in the year.

The literature is full of other examples that show the effect of metering. In Gothenburg (Sweden) the per capita use in apartment blocks with one meter for all units is reported to be 50 percent higher than in the single houses with metered connections. In the Hague (Netherlands), residential water consumption is reported to vary with respect to both metering and type of bathing facilities:

	Water use in liters/caput/day	
	Showers	**Bath tubs**
Single house with meter	86	121
Apartment building with one meter	106	140
Apartment building with no meter	126	171

Pricing

Although several studies have included "price" as an explanatory variable in water use models, the evidence has not been widely accepted because of inherent data problems and a reluctance to entertain the notion that residential water use varies with respect to price. It is pointed out that water is not a significant item in the family budget and that there are hardly any substitutes for residential water. The first assumption may or may not be true, depending on income levels. The second assumption may be questioned: less frequent sprinkling, a smaller lawn area, a rock garden, smaller toilet tanks and the prompt fixing of faulty plumbing fixtures are some of the "substitutes" for water use.

One can point to several empirical studies that suggest that urban water use is a declining function of price. However, such empirical results have to be used with some caution and are comparable only in a very general sense. The coefficients are based on data referring to different measures from different groups of cities, for different time periods, using differing functional forms of the demand equation. Two problems may be selected for further comment.

Some empirical studies include all urban water uses. Depending on the proportion of total water use taken by industrial and commercial

customers, one may argue that the water use-price relationship may well reflect the fact that firms using a lot of water choose to locate in cities where water costs (and consequently "prices") are low. Therefore, one obtains a spurious demand function.

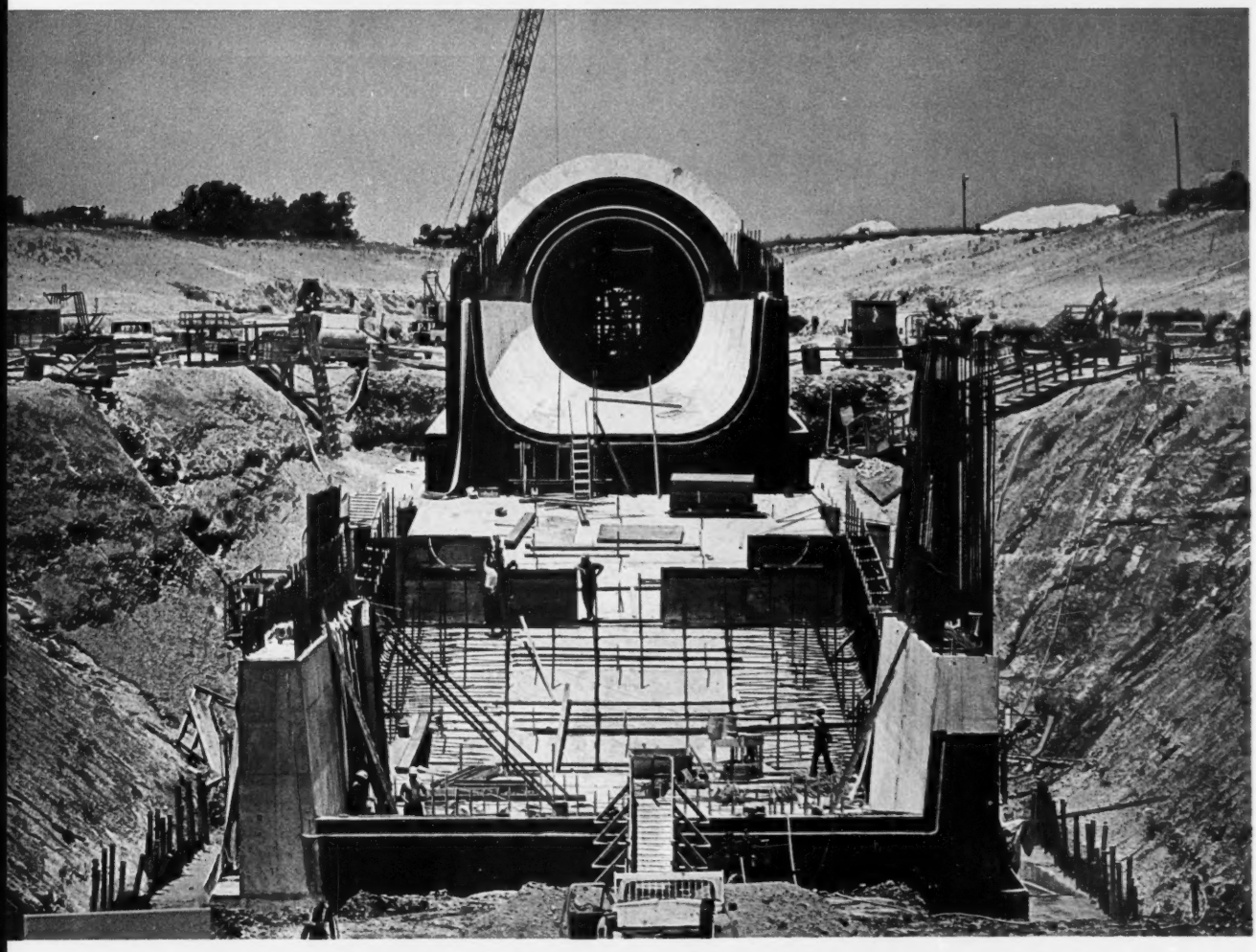
Even when residential water use only is included there may be some problems. Residential water rates often decline with quantity; if there is a change or step in the water rates within the usual range of residential water use, low water users pay a high price for water and high water users pay a low price. Under these circumstances one obtains an equation that describes price to be a function of water consumption, rather than an equation that predicts water use as a function of price. A study in the U.S. used averages of water use obtained from master meter readings of small groups of residential consumers. The price responsiveness for indoor uses is predictably low; the price elasticity is −0.22. The price responsiveness for sprinkling uses is much higher.

Policy Variables: Impact on Investment

Residential water demand management aims at the conservation of water, in order to make a more efficient use of the resources that the community allocates for the provision of residential water of the required standards. By influencing water demands, management can affect the level and timing of additional plants or equipment required to meet the demand. Not all investment costs are affected if the demand for water is reduced; the fraction of total costs would depend on local conditions. A review of the literature suggests that the development of sources, the provision of pumping and purification facilities and the provision of local storage to meet peak demands are affected directly by a reduction in the demand for water.[2] Expenditures on main

Expenditures for conduits and mains are affected only marginally by a reduction in water demand.

[2] A. P. Grima, *Residential Water Demand: Alternative Choices for Management*, Toronto: University of Toronto Press, 1972.



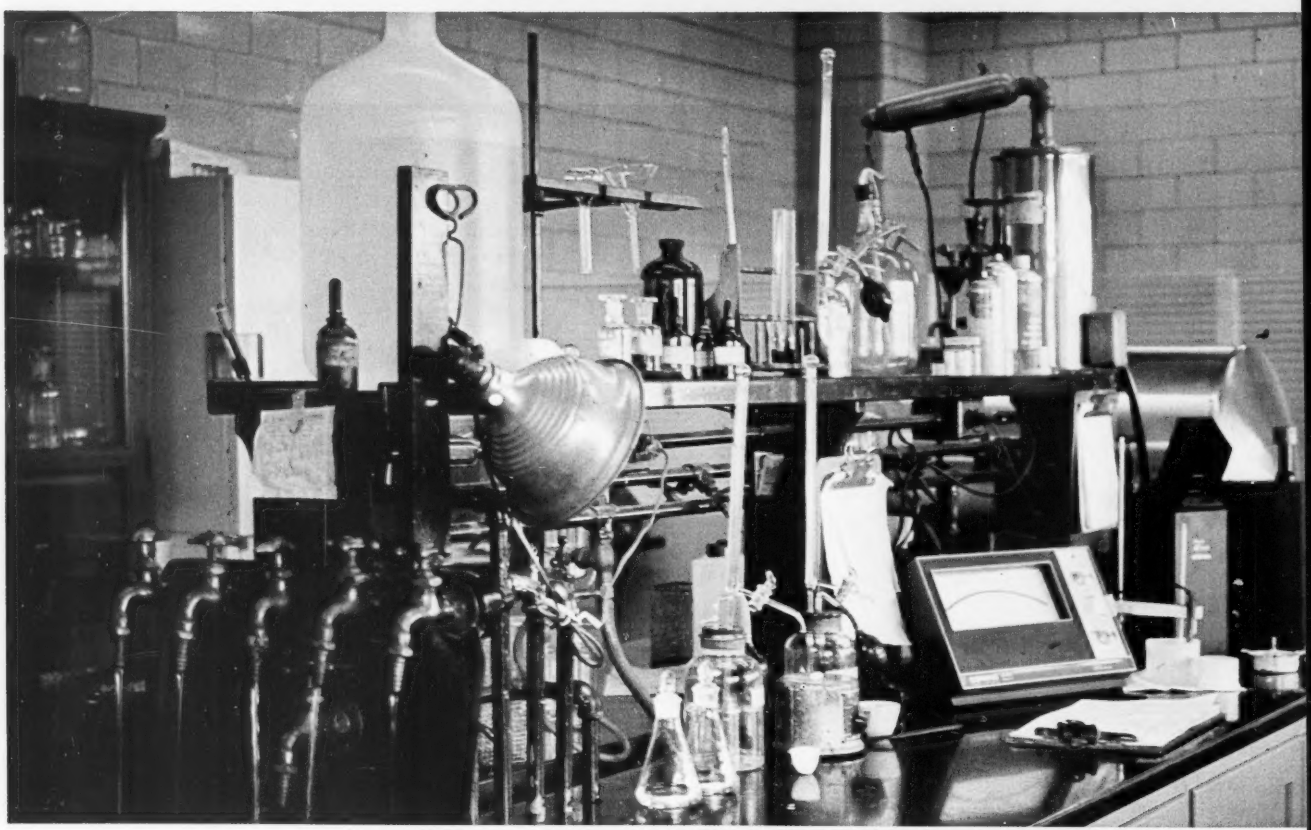
transmission and local distribution are affected only marginally by a reduction in the demand for water. It seems reasonable to assume that some 60-70 percent of capital investment in residential water supply is affected by changes in the level of water demand on the maximum day.

In the Toronto Study an attempt was made to estimate the impact of policy alternatives (e.g. metering, increase in marginal charges) on summer water demand and, by implication, on investment requirements. These applications are offered as worked examples given the assumed conditions; such conditions do not apply universally, but the method is capable of replicability.

The *new* community served by the design system is assumed to have a population of 200,000 people living in 50,000 single-unit dwellings; the level of required investment per resident for residential water supply is assumed to be $150. It is further assumed that changes in capacity demand on a summer day have a proportionate effect on 0.65 of this required investment. These assumptions could be changed in other applications; the chosen size of community obviates the difficulty of interpreting results with respect to fire protection demand and economies of scale. A fixed bill of $1.50 per billing period is also assumed for purposes of computation. A new community is specified in order to make it possible to apply the fitted equations directly; these equations are derived from cross-sectional (or spatially distributed) data and would apply to price changes over time only in the long-run (i.e. over a period of time sufficiently long to allow consumers to adjust to higher marginal charges, e.g. by having faulty equipment repaired).

The results from the Study show that the change from an unmetered situation to metering and a marginal price of .50 cents per thousand gallons would reduce residential water use in summer by 39 percent. The saving in investment would be about 7.5 million dollars.

It should also be kept in mind that metering is not a cost-free alternative. Meters have to be purchased, installed, read and maintained in working condition. The main benefit of metering is the saving in investment required to meet the water demand that would occur in the absence of metering. This saving will also be reflected in



Water quality *must be considered along with* quantity. *Fire protection, and most industry, does not require the degree of treatment that in-house use does.*

design capacity requirements for sewage treatment plants.

Also, a rational consumer would try to use less water (and reduce his water bill) in response to the *marginal* price. If the fixed charge (or the price for the first few gallons) is increased, the rational consumer realizes that reducing the water consumption by a small amount would not reduce the water bill.

If a water utility operating in the range of increasing costs charges the marginal cost price, its revenues would exceed total costs. The difference could either go to the general tax fund or be used to supply each consumer with a small quantity of free or low cost water. The increasing block rate would reflect the increasing costs of providing more water and lead to a more efficient use of investment resources.

Pricing Municipal Water: A Case Study

Before one can formulate theoretically more rational pricing policies for municipal water use, one has to examine the variables that affect the *actual* water rates. The water rates are set to cover costs and this would imply that the water rates are related to average costs. This hypothesis was tested by the author in the 43 largest municipalities in Ontario. Part of this research compared the average cost of municipal water with the water rates charged to five classes of users—ranging from consumers who use 5000 gallons/month up to consumers using 2 million gallons/month. The period of observation was the 1960s, since the published data was most complete for these years.

One of the findings is the large range in the average cost: St. Catharine's supplies water at a cost of 13 cents/1000 gallons; Bertie Township, a few miles away, charges 70.2 cents. Thirty of the 43 municipalities supply water at 22 to 48 cents/1000 gallons (i.e. within one standard deviation of the mean).

Average cost is indeed a significant, explanatory variable of water rates at each user level, but it does not fully explain the variance. Non-cost factors contribute 70 percent or more to the variance in water prices.

Municipalities are believed to favor average-cost pricing but the evidence suggests that rates are not related in large measure to average cost and therefore a rationalization of water rates in Ontario seems to be desirable. Thirteen municipalities sold water to large consumers at such an absurdly low price that not even average operating costs are covered.

In half of the municipalities the marginal costs were rising but had not yet equalled average costs; in such cases the widely used declining block rate would still be the correct pricing approach provided the marginal costs are met. In the other half of the municipalities the average costs were exceeded by the marginal costs and the declining block rate would no longer be defensible.

Previous studies in Canada and the U.S. provide strong evidence that residential water use *is* responsive to the level of pricing. Despite the importance of urban water supply and the fact that pricing is virtually the only policy instrument for regulating its use, current practices *appear* to have many deficiencies. Parts of New York, Toronto and Hamilton do not even meter water to residential users. When meters are used, the price is set to recover expenditures, not to reflect the incremental (or marginal) cost which economists regard as critical to efficient use.

Urban water supply has evolved a long way from the well . . . it has almost as far yet to go.

In most instances the water which is most expensive to produce (i.e. the water made available on the maximum day) is priced at a lower rate than the remainder of the consumption—since the last units of water consumption on a hot, dry day are charged at the lowest rate on the declining block rate.

It is clear that a more rational approach to water rates could have substantial payoffs in reducing pressure on required investment for municipal water supply and sewage treatment. Reductions in water use and subsequent effluent discharges would also reduce pressures on water quality in lakes and rivers which contribute so much to our natural heritage. ■

short take

Pollution, Contamination and Common Sense

by **Philip W. West**

The semantics trap. It seems that words fail when water quality is discussed. The lay definition of the words "contamination" and "pollution" is brutal: the dogmatic, finite position that anything contaminated or polluted is unfit. Our vocabulary seems inadequate because of the void existing between the term "pure," at one end of the spectrum, and those of contaminated or polluted, at the other. The connotation applied to contaminated/polluted is consistent with the usual dictionary definitions, while for the word pure there is a general disregard for the absolute significance of the term.

Pure water. What is it and who needs it? Very few people want or need "pure" water. Even school children know that pure water is H_2O: two atoms of hydrogen and one of oxygen are combined to form a molecule, which, at normal temperature and pressure, exists in liquid state. It is exceedingly difficult to produce pure water and it is even more difficult to maintain it in a state of purity—because the molecular oxygen and carbon dioxide of the air are water soluble and thus tend to "contaminate" water the moment it is exposed. Water having a high degree of purity is required occasionally—by chemists, for example, who are making special studies. Except for such exacting cases, however, ordinary distilled water suffices for all routine chemical work. Physicians require pure water, but ordinary distilled or deionized water suffices—provided the water is sterile. Because most people are not really concerned with absolute purity, the following statements can be directed toward what might be called "environmentally pure" water.

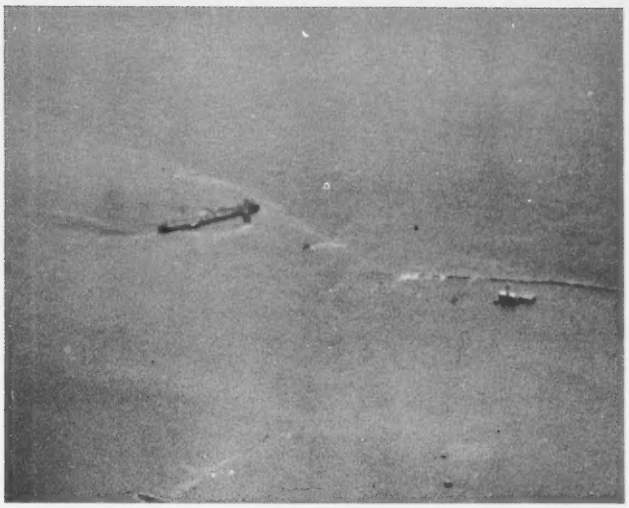
Again, the problem of semantics makes it difficult to discuss the quality of water from the environmental standpoint. First, it must be agreed that absolutely pure water not only cannot, but should not, exist in the environment. Natural waters must contain substances such as dissolved oxygen, carbon dioxide, iron, copper, zinc, manganese, etc. Such species possibly could be termed additives, but the term additive also carries an adverse connotation for many people and may also imply that the material in question has been introduced through some conscious effort. Probably then, the best approach is to continue the use of the familiar terms, but to define them in the context of environmental discussions. Thus, contaminant may be defined as an addition to the pristine state of the environment. Pollutant may be defined as a contaminant that adversely effects something that man values, and that is present in sufficient amounts to do so. Possibly, as an afterthought, the term fortified might be substituted for contaminated or polluted.

Beautiful, clear waters of the Bahamas—lovely to see, but unproductive because of the lack of nutrients. (Photos by the author)

Because that nature and degree of contamination is so important, it should be realized that contaminants can be classified as essential or nonessential. Also, they may be termed as persistent or as transitory. Obviously, true pollutants are most often nonessential, persistent species that accumulate or are added in relatively large amounts. One cannot condone such environmental burdens. Transitory species will be discussed later from a more compassionate viewpoint.

Environmental contamination, as defined and restricted to the water environment, in no way implies impairment. Instead, water in the pristine state will seldom have adequate nutritional value and the introduction of essential nutrients merely fortifies or supplements. These waters obviously contain necessary dissolved oxygen and carbon dioxide but are most unlikely to contain a balance of iron, copper, manganese, zinc and other essential trace elements. They are unlikely to contain enough organic

Dr. West is on the faculty of the Environmental Sciences Institute, Department of Chemistry, Louisiana State University, Baton Rouge.



Waters of the Gulf of Mexico at the southwest pass of the Mississippi River. The waters are murky and polluted, but very productive.

matter to provide food for aquatic organisms. If water is to play a role in providing food, and millions of people depend on this, then supplemental contaminants are necessary and a case can even be made for a bit of transitory pollution!

Before readers become upset, let it be said that some waters should be valued for their aesthetic and recreational properties only. Such waters should be clear and pure enough for swimming and fishing. In this connection, some fishermen will point out that fish are found in clear mountain streams in pristine areas. Admittedly, there are enough trout in Colorado to satisfy the sportsmen but certainly there are not enough fish to feed the people in Denver, or even Aspen. It is also interesting to note here that the trout get much of their food, directly or indirectly, from the air—in the form of insects and their larvae. The fishing in such "pure" mountain streams is done by fly-casting.

Turning now to productive waters, it is quite apparent that absolute purity is out of the question. If the Mississippi River passing Baton Rouge and New Orleans consisted of distilled water there would be no seafood industry such as we now have in Louisiana. Without copper "contaminating" the water there could be no oysters. Traces of iron, manganese, cobalt, copper and zinc are essential for the crabs, snapper, flounder, shrimp and other creatures that abound in the Gulf waters. As unpleasant as it sounds, even the runoff from the fertilized fields of the heartlands and the sewage discharges into the Missouri, Ohio and Mississippi River systems pollute and thus ultimately nourish the waters.

The term "biodegradable" provides insight into the value of organic matter that is biologically decomposed and thus serves as food for the organisms involved in the degradation. The sewage, for example, is a transitory pollutant. The first organisms that are involved in degrading the sewage are in turn consumed by larger and more complex organisms, such as zooplankton and phytoplankton, and thus initiate the food chain.

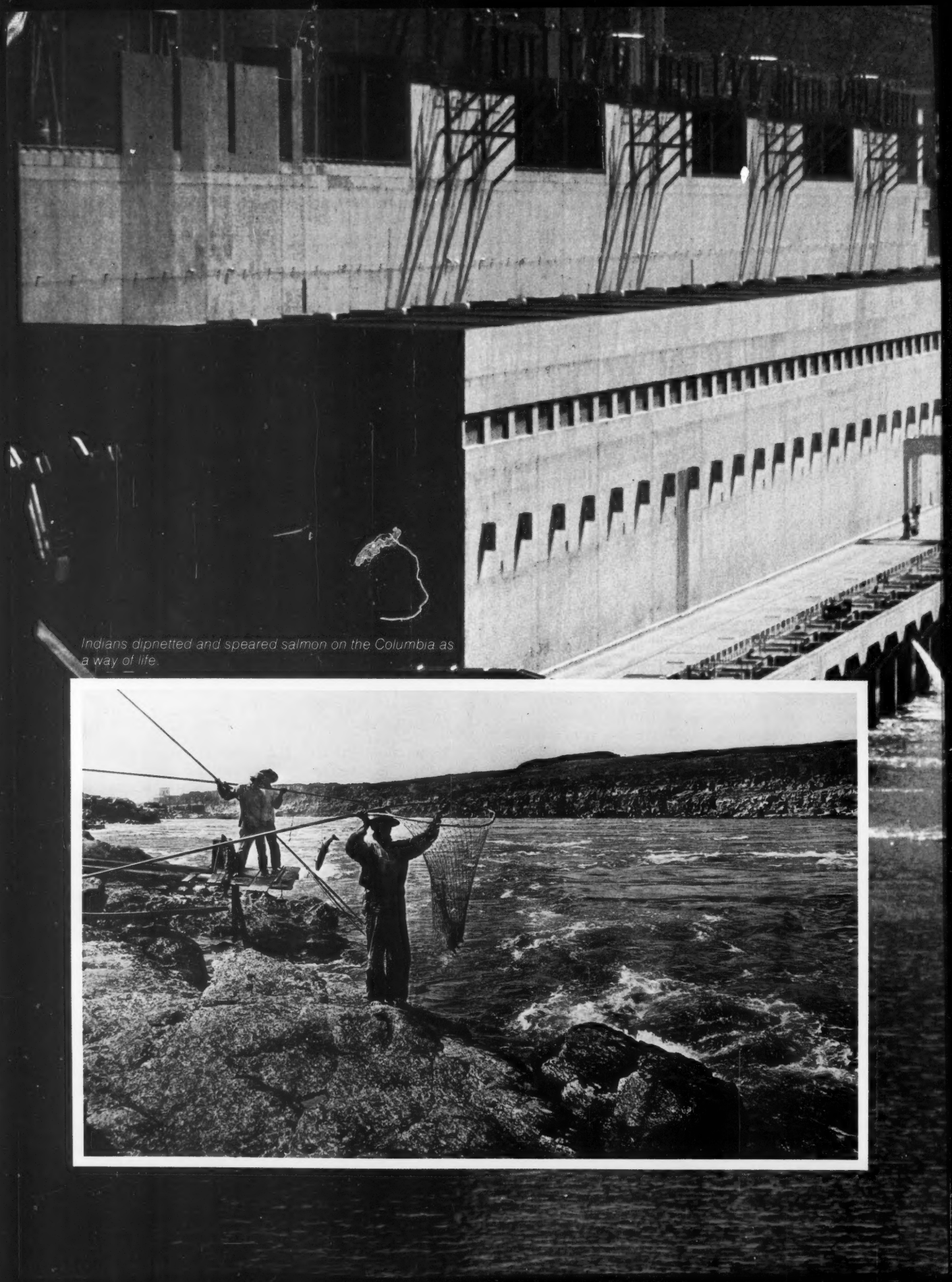
The evidence favoring reasonable contamination and even pollution can be seen from a consideration of seafood production areas. The enrichment resulting from the discharges of the Mississippi, Potomac, Hudson and St. Lawrence Rivers contributes to the vast tonnage of seafood generated in the Gulf of Mexico, the Gulf Stream and the New England and Nova Scotia fishing grounds. The significance of the enrichment from the land can be appreciated when one observes that international fishing is a matter of concern because it centers near the coastal borders. If the fish were to be found in quantity in mid-ocean there would be very little problem over fishing rights.

A dramatic illustration of man's contributions to the support of fish populations can be obtained from the Gulf Stream, which carries the organic and inorganic nutrients from the Mississippi and lesser rivers emptying into the Gulf. Sportsmen go to the Bahamas to fish, with most activity out of Bimini. Working the waters to the west, between Bimini and Florida, angling efforts are rewarded because of the abundance provided by the Gulf Stream. Fishing to the east of Bimini is less rewarding because the waters are less benefited by man. The population of the Bahamas is not sufficient for discharging the necessary nutrients to support abundant fish populations. Although the waters surrounding Grand Bahama, Eleuthera, the Exhumas and other nearby islands are spectacularly clear and beautiful, little commercial fishing is possible. Seafood production is limited to a few bonefish, some lobsters and conch.

"The point is that we must have contaminated water. Absolutely must have it. Animals and plants do not live in pure water . . . People have become much to emotional about pollution and wrongly treat contamination as a dirty word . . . the overpurification of water can cause 'real' trouble by disturbing the natural order of animal life. . . ."

This short article has tried to make a case for contamination and even pollution. Hopefully, little apology is required in the case of contamination. For pollution, however, only the transitory, biodegradable and nutrient varieties are to be accepted. For such varieties, the environmental impact must be controlled so that any stress imposed is relieved within a reasonable time and distance. The benefit must outweigh detrimental impact.

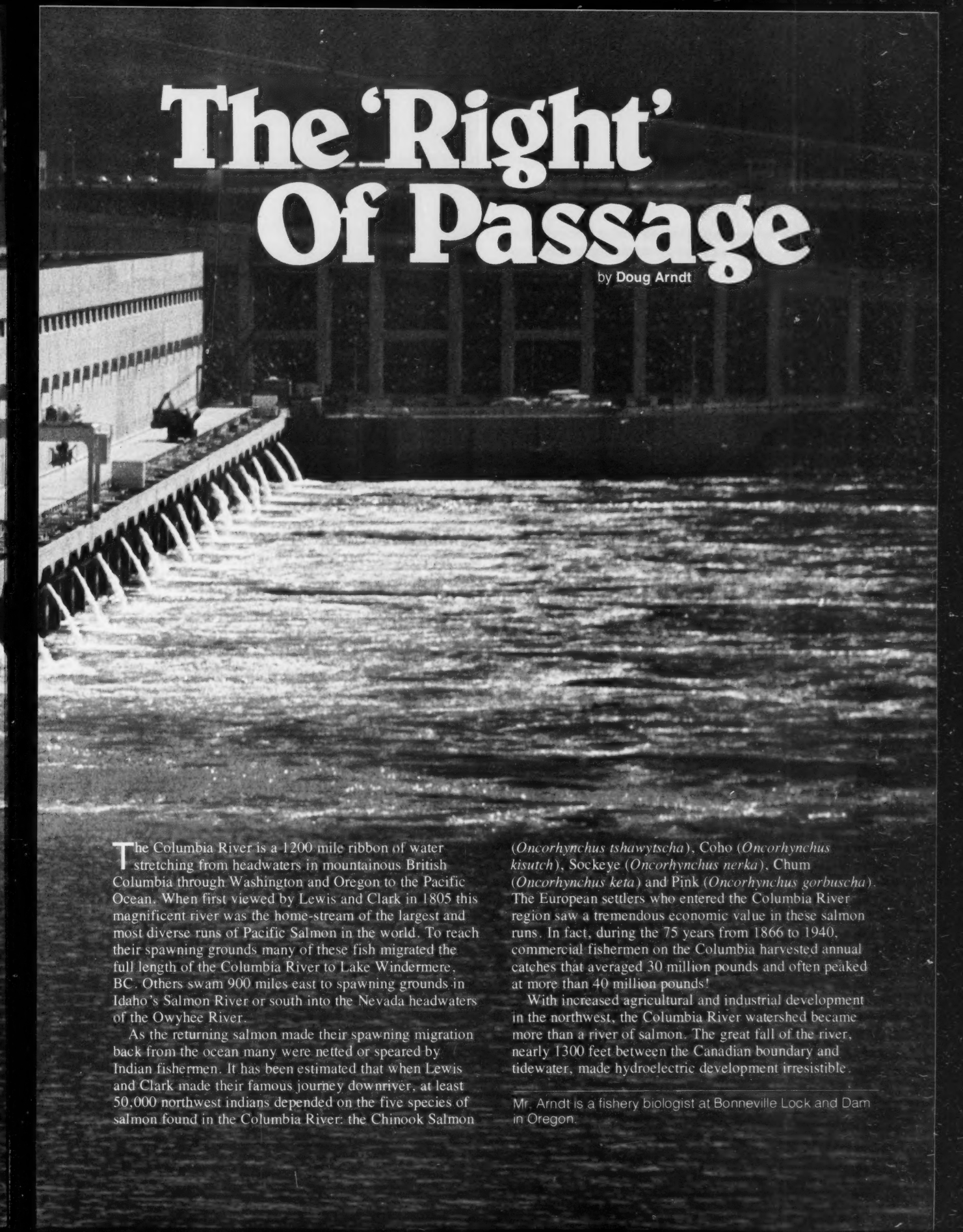
Since any discussion should have a purpose, the plea is made here for qualified, responsible individuals and agencies to exert influence by knowledge and reason and not by blind emotion and popular appeal. Eliminate or minimize the pathogens, PCBs, heavy metals, radioactive species and other true pollutants, and control those materials that can provide ultimate good. ■



Indians dipnetted and speared salmon on the Columbia as a way of life.

The 'Right' Of Passage

by **Doug Arndt**



The Columbia River is a 1200 mile ribbon of water stretching from headwaters in mountainous British Columbia through Washington and Oregon to the Pacific Ocean. When first viewed by Lewis and Clark in 1805 this magnificent river was the home-stream of the largest and most diverse runs of Pacific Salmon in the world. To reach their spawning grounds many of these fish migrated the full length of the Columbia River to Lake Windermere, BC. Others swam 900 miles east to spawning grounds in Idaho's Salmon River or south into the Nevada headwaters of the Owyhee River.

As the returning salmon made their spawning migration back from the ocean many were netted or speared by Indian fishermen. It has been estimated that when Lewis and Clark made their famous journey downriver, at least 50,000 northwest indians depended on the five species of salmon found in the Columbia River: the Chinook Salmon (*Oncorhynchus tshawytscha*), Coho (*Oncorhynchus kisutch*), Sockeye (*Oncorhynchus nerka*), Chum (*Oncorhynchus keta*) and Pink (*Oncorhynchus gorbuscha*). The European settlers who entered the Columbia River region saw a tremendous economic value in these salmon runs. In fact, during the 75 years from 1866 to 1940, commercial fishermen on the Columbia harvested annual catches that averaged 30 million pounds and often peaked at more than 40 million pounds!

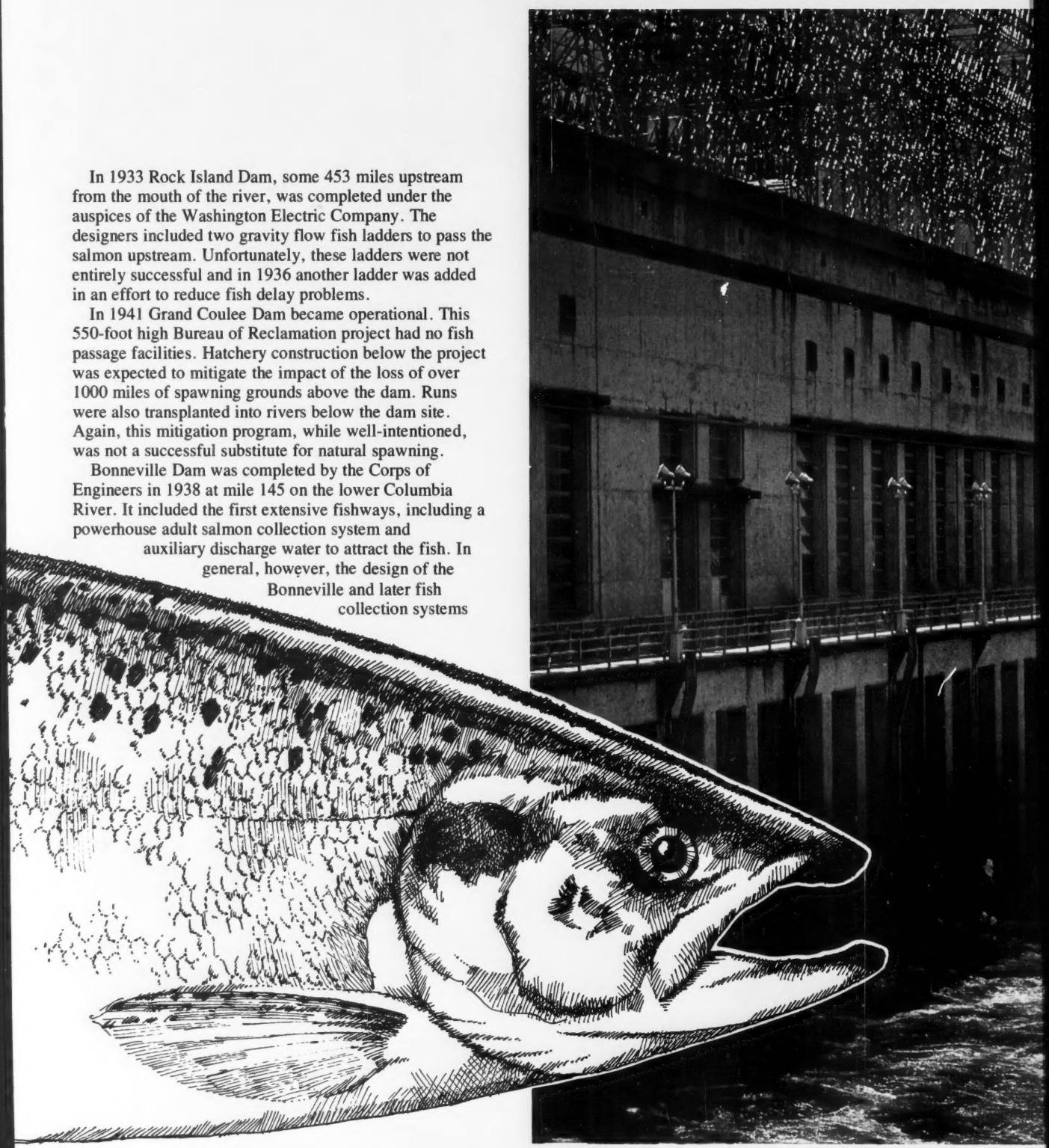
With increased agricultural and industrial development in the northwest, the Columbia River watershed became more than a river of salmon. The great fall of the river, nearly 1300 feet between the Canadian boundary and tidewater, made hydroelectric development irresistible.

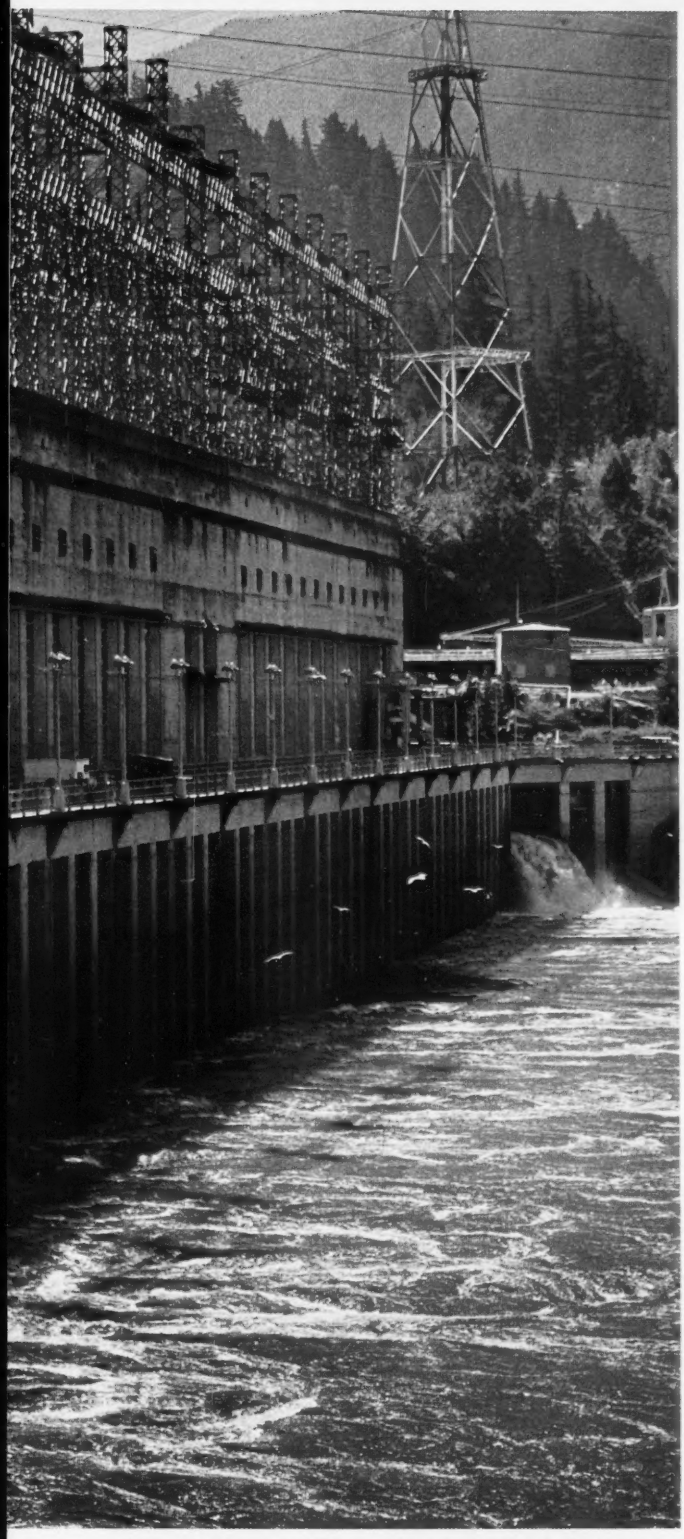
Mr. Arndt is a fishery biologist at Bonneville Lock and Dam in Oregon.

In 1933 Rock Island Dam, some 453 miles upstream from the mouth of the river, was completed under the auspices of the Washington Electric Company. The designers included two gravity flow fish ladders to pass the salmon upstream. Unfortunately, these ladders were not entirely successful and in 1936 another ladder was added in an effort to reduce fish delay problems.

In 1941 Grand Coulee Dam became operational. This 550-foot high Bureau of Reclamation project had no fish passage facilities. Hatchery construction below the project was expected to mitigate the impact of the loss of over 1000 miles of spawning grounds above the dam. Runs were also transplanted into rivers below the dam site. Again, this mitigation program, while well-intentioned, was not a successful substitute for natural spawning.

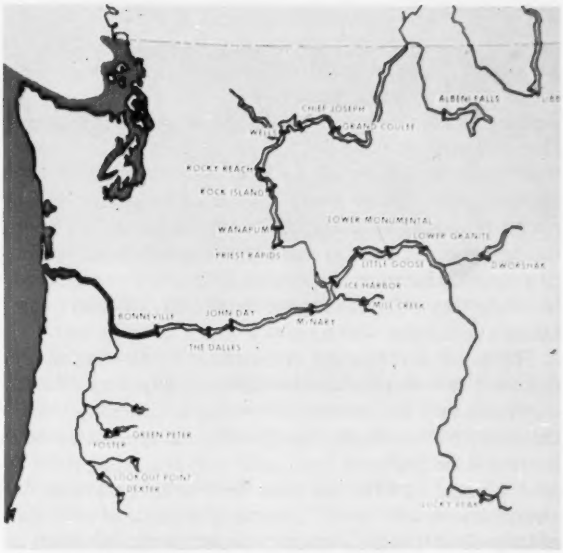
Bonneville Dam was completed by the Corps of Engineers in 1938 at mile 145 on the lower Columbia River. It included the first extensive fishways, including a powerhouse adult salmon collection system and auxiliary discharge water to attract the fish. In general, however, the design of the Bonneville and later fish collection systems





Bonneville Lock and Dam, completed by the U.S. Army Corps of Engineers, was the first Columbia River project to incorporate extensive salmon passage facilities.

was based on prior knowledge and laboratory studies. The overwhelming turbulence, depths and size encountered at the actual project made in situ evaluation nearly impossible. As a result, modifications in fishway design or operation were made only when visual observations or accidential discovery revealed a severe fish passage problem.



The Columbia River and its tributaries provided spawning grounds for millions of Pacific Salmon.

Efficient salmon passage was not as critical 30 years ago with the few dams then operating in the Columbia River system. But this watershed now has 13 mainstem hydroelectric dams and over 100 tributary dams. In the past ten years, the combination of industrialization, irrigation and intensive fishing, as well as the multiple obstacles created by the dams, has focused attention on the drastic decline in the once plentiful Columbia River salmon runs. It has now become imperative to act decisively or face the complete loss of the fish.

To collect the necessary information to rebuild the salmon runs, the Corps of Engineers, in cooperation with the Northwest fishery agencies, has initiated a broad-based research program. The program explores all facets of juvenile and adult salmon migration in an effort to identify and, if possible, correct those factors associated with the construction and operation of hydroelectric facilities which cause excessive fish delay or mortality.

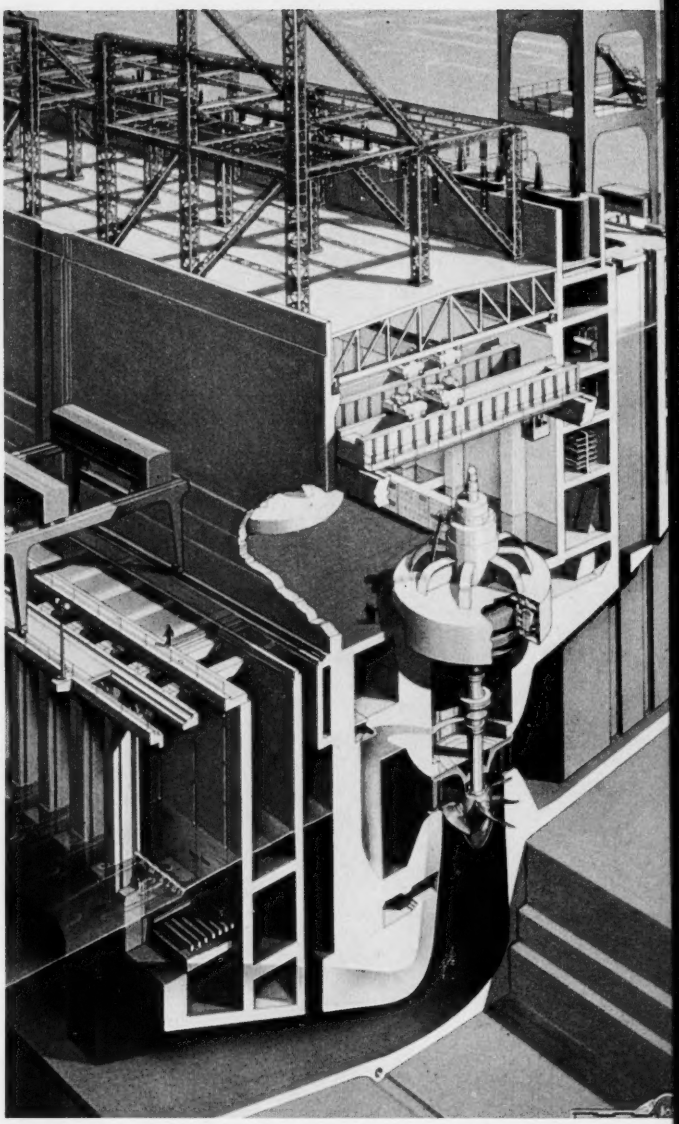
The Corps of Engineers Portland District Fishery Research Team is charged with the responsibility of evaluating the effectiveness of the adult salmon fish passage facilities at the dams. These fish passage facilities must attract, collect and pass the fish upstream effectively if the salmon are to reach their spawning areas and perpetuate the species.

The problems associated with a fish passage system evaluation are complex and extensive. A typical Columbia River hydroelectric powerhouse may be over a quarter mile long and have an adult fish collection channel that extends along its entire face. Armed with the knowledge that salmon are attracted by flow, designers spaced numerous slots and orifices along the channel to provide the salmon entry from the tailrace. Up to 5000 cubic feet/second (cfs) attraction and passage water flows from the combined openings. A single channel at The Dalles Dam, for example, pours out 1000 cfs. This is equivalent to the flow of a modest size river. Additional difficulties encountered in conducting an evaluation are the depths, velocities and tailrace turbulence which prohibit visual observations.

The recent development of electronic monitoring and detection devices provides the means of acquiring accurate information on the location and timing of fish entry into these collection systems. Specifically, the approach used to overcome the problems associated with evaluating the adult passage facilities has been the development of an "electronic tunnel" array. This array consists of a number of large (2'x6') tunnels made of coated marine plywood or painted stainless steel. Each tunnel has a set of electrodes extending lengthwise along the inner walls. The conductivity of the water between these electrodes forms an electrical resistance which is used as two arms of a balanced bridge circuit. The other two arms of the bridge are made up of a number of resistive and capacitive elements within a separate detector-counter.

To operate, the bridge is balanced manually at the detector-counter. When a fish passes through the tunnel the resistance between the electrodes changes, causing the bridge to become unbalanced. This unbalance signal activates a counting register in the detector-counter, and records a count. The detector-counter not only senses the presence of fish in the tunnel, it can also determine the direction of passage through the tunnel.

By placing the tunnels at all fish entry locations on the powerhouse collection system, the individual and total upstream and downstream fish passage counts can be accurately determined. Hourly counts through each orifice and channel are compiled and analyzed to reveal real and relative passage rates at that location. These fish counts are also correlated with other data such as turbine and spill flow, river velocities, and upstream fish passage to reveal problem areas.



A typical Columbia River Dam powerhouse with the integrated fish collection system in front. The size and complexity of these structures is evident.

To gain more information on salmon movement at the dam additional techniques have been adopted. One of the newest techniques to be added is radio telemetry. This involves using adult salmon with internal radio transmitters. National Marine Fisheries Service personnel, who incorporated radio tracking into their Columbia River research program, were able to continuously locate the fish during their spawning migration. By developing a fish collection channel antenna system, fishway monitors, and by concentrating and intensifying the tracking just below the powerhouse, the technique can be used to determine how individual fish approach the collection system, respond to the entrance conditions and react once within the collection and ladder facilities.

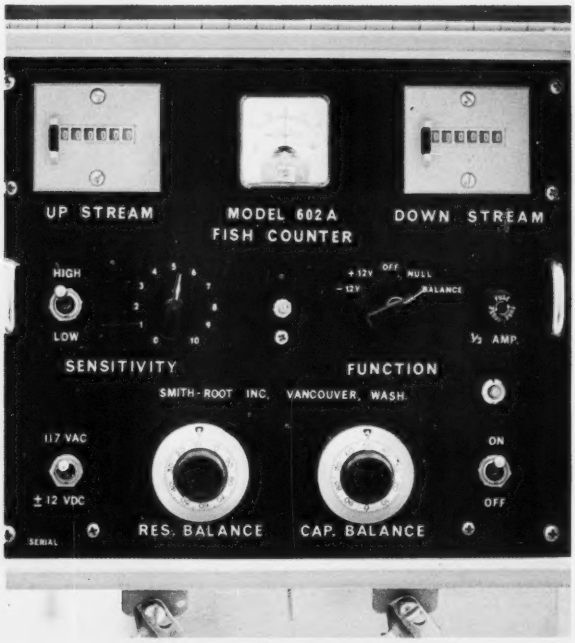
To obtain adult salmon for radio-tagging, a fish is

live-trapped and anesthetized. The fish then has a radio tag inserted through the esophagus into its stomach. The fish is immediately placed into a recovery tank. After it has been determined that the fish is fully recovered and swimming normally, it is hauled by a special fish-holding transport truck to a release site below the dam.

Tracking stations are positioned at sites along the tailrace in close proximity to the powerhouse. As the tagged fish swim toward the collection and passage facilities, the radio signals are received by personnel manning the stations. The multiple compass bearings are called into a plotting station where they are integrated into triangulated plots. This results in a continuous track as the tagged fish approach, enter and leave the powerhouse fish collection system. By combining radio-tagging and electronic tunnel information, a composite picture of fish passage emerges.

At present, the adult salmon passage facilities at the three lower Columbia River dams (John Day, The Dalles, Bonneville) have been evaluated using one or both of the techniques. The entrances used by the adult salmon have been pinpointed and the entry rate measured. The information has been correlated with fish facility and powerhouse operations and is being used to enhance salmon passage conditions.

An important concern of powerhouse designers and fishery biologists is the blockage of adult salmon at the



An electronic tunnel and associated counter-detector (below, left) was used to count adult fish at the dams.

powerhouse collection entrances by upwelling discharge water from an adjacent turbine. The fish may not be able to find their way through the turbulent upwelling and into the collection channel because of a loss of directional attraction water. At John Day Dam, for example, it has been discovered that the 25,000 cfs discharge flow from the turbine nearest shore successfully attracts adult salmon, but the turbulence created as the water boils to the surface overrides the much smaller 1000 cfs attraction flow from the adjacent powerhouse fish collection channel.

In future construction of dams this problem will be avoided by designing the entrances so that they are located upstream or to the side of the turbine flow upwelling. At the existing John Day Dam, reconstruction of the entrance would be expensive and shutdown of the turbine impractical. This particular problem has been significantly reduced, however, by reducing the adjacent turbine discharge during fish runs. The resulting upwelling now surfaces some yards downstream from the entrance, allowing unrestricted fishway attraction flow. The net result is a smooth transition in flows from tailrace into and through the powerhouse collection system.

Perhaps the most significant finding to date has been the discovery that most of the powerhouse adult fish collection systems at the projects have been over-designed. That is, the systems incorporate many more fishway entrances than is necessary. At The Dalles Dam, for example, it was discovered that during all the salmon runs there was minimal fish entry into 20 of the 25 collection system entry orifices. Most of the salmon entering the collection system did so through the five orifices at one end of the powerhouse. As a result, a major portion of the available

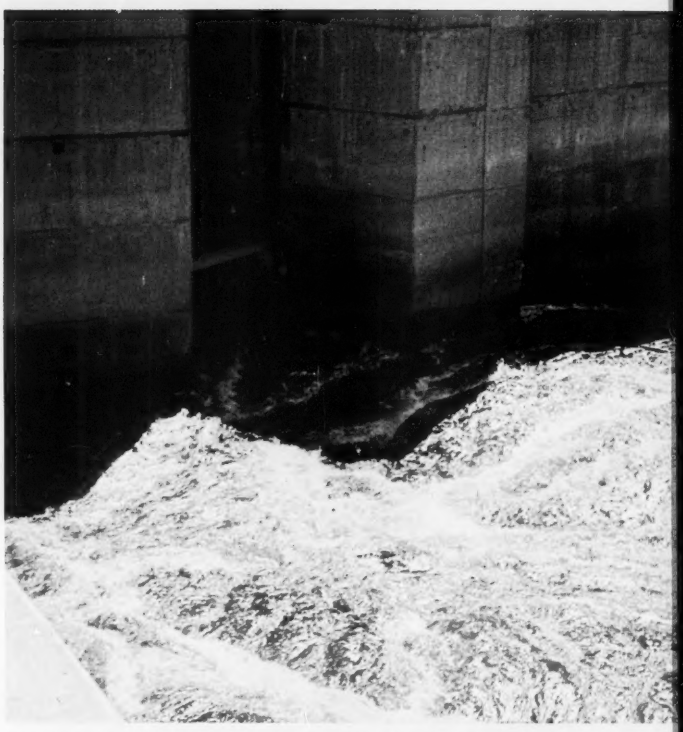
fish attraction water was not being effectively used. Experimentation revealed that the water could be diverted to entrances in the area of high fish passage. In doing so, the entry and passage rate at The Dalles Dam has been significantly enhanced.

Another striking instance of over-design was found at Bonneville Dam. The powerhouse collection system at this project incorporated 22-2′x6′ orifices and two entry channels spaced evenly along its 1000 foot distance. After analyzing the fish count data it became evident that many of the entrances actually allowed salmon to fall out adjacent open entrances as they traversed the face of the powerhouse in the collection channel. After falling out, some fish moved far downriver before returning to re-enter the collection channel. Fifteen of the entrances not used by the salmon were closed and the water diverted to the preferred entrances (primarily at the ends of the powerhouse). The salmon now enter and pass through the collection channel with a greatly reduced risk of fall back.

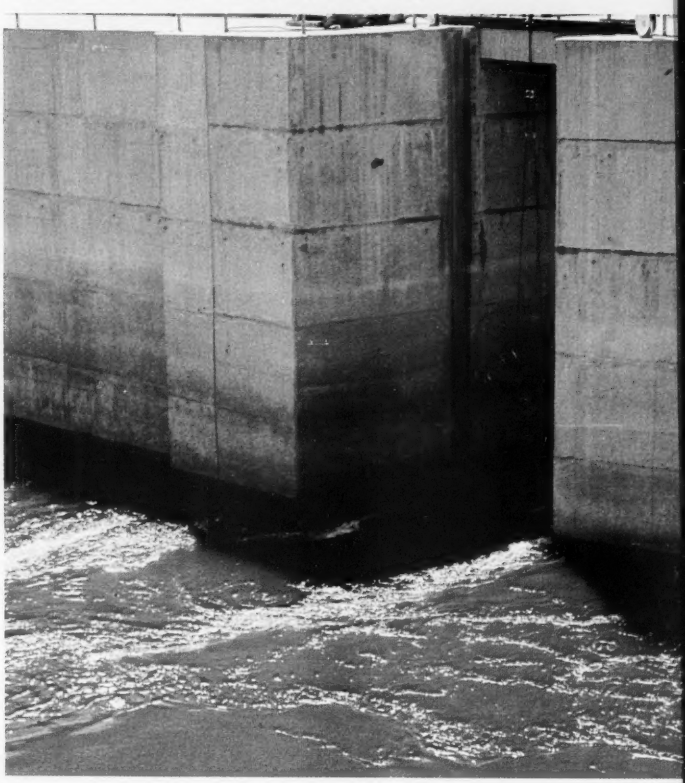
One aspect of hydroelectric power production which is controversial in the Pacific Northwest is daily power peaking. Briefly described, this is a fluctuation of electrical power (and thereby waterflow through the turbines) depending upon consumer demand. Generally, there is a sharp increase in the power demand on weekday mornings as people get ready for work and factories begin operation. To meet the demand there is an immediate and large boost in waterflow through the turbines. Downstream from the powerhouse the river velocity jumps. During mid-day there are small flow oscillations followed by a sharp drop at night when power demand falls off.

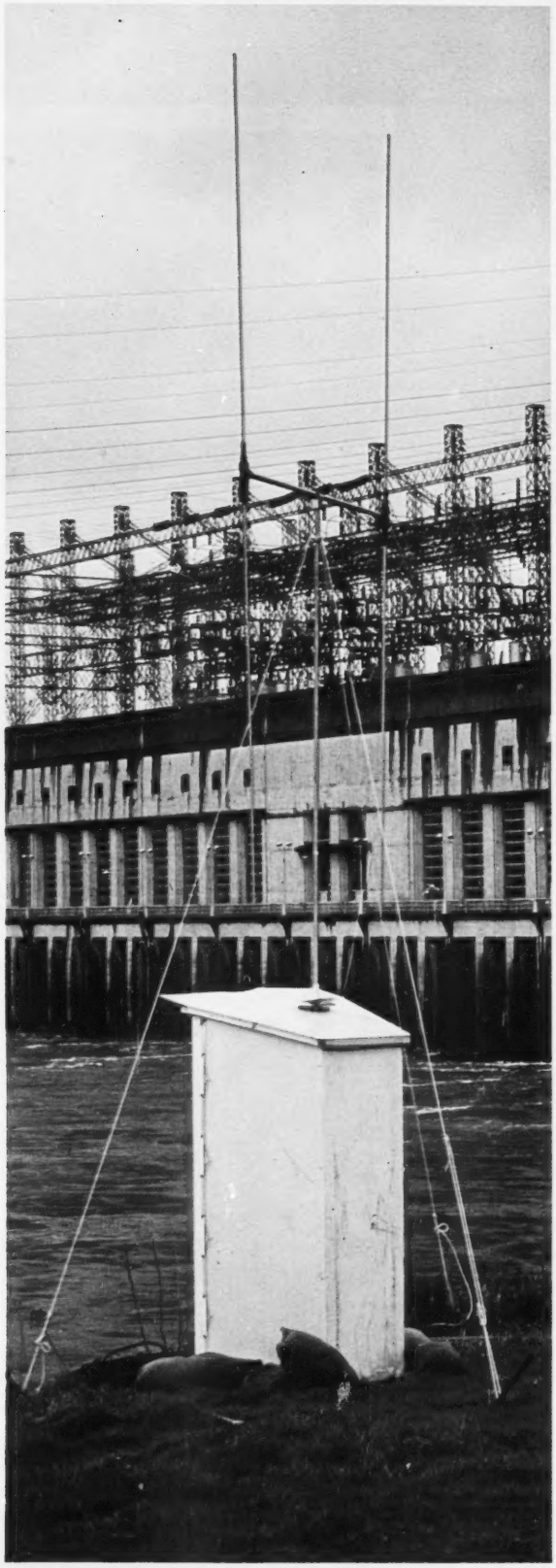
The impact of those riverflow fluctuations upon adult salmon approaching the dam is not completely understood. Certainly, drastic water velocity changes along the fishes' migration route may affect their movement. If serious, this impact should be evident in the hourly fish counts through the powerhouse collection system entrances.

The Portland District Fishery Research Team selected The Dalles Dam during the spring and fall chinook salmon runs to look at the effects of peaking on salmon passage. To obtain the peaking conditions, three 100 MW turbines were operated together at high and low discharge levels and fluctuated at two diferent rates. Counts of adult salmon entering the collection channel were taken hourly during each of the flow conditions. An analysis of the resulting data revealed that the salmon entering the collection system were not affected by the discharge levels nor the fluctuation rates. Apparently the fish key upon the flow from the turbines and will accept substantial changes in that flow without an adverse reaction. Additional research the following year did suggest that when the water velocity in the tailrace reaches as high as 7-8 feet per second (fps)



The turbulence created by turbine discharge in front of a salmon entrance inhibited their movement past the dam. Reducing turbine flow slightly moved the turbulence downstream and significantly improved entry conditions.





some fish are forced to search for different passage routes.

Our ability to detect the location and rate of adult salmon entry into the powerhouse collection system by use of the electronic tunnels is very effective. But to learn the movement pattern and behavior of the fish as they approach the powerhouse we found radiotracking invaluable. Our experience with the technique has convinced us that an evaluation of hydroelectric fish passage facilities can be greatly enhanced by intensive radiotracking.

During the 1978 spring salmon run at Bonneville Dam radiotracking was used extensively. Sixty-eight tagged, spring chinook salmon were released below the dam and tracked by radio telemetry. Several important and somewhat surprising facts became evident. When the fish swimming along the south shore approached the powerhouse many suddenly veered across the tailrace to the other shore where they entered the collection channel. Armed with this knowledge we investigated further. The probable cause was discovered to be the excessive velocity (8-11 fps) encountered in the tailrace at some powerhouse turbine discharges.

After exiting the fishladder into the forebay the salmon are exposed to an additional problem. Those fish which stray into the area near the operating spillway gates may be swept back downstream. During the 1978 spring run, over 20 percent of our tagged fish were carried down through the spillway. Fortunately, while the fish were delayed one to two days before recrossing the dam, none were killed or even seriously injured. A netted lead from the fish ladder entrance is presently being tested to prevent the fish from approaching the spill area. To date this has met with partial success.

The search for more efficiently designed salmon passage facilities continues. Although designers are incorporating the most up-to-date passage facilities into the Bonneville Second Powerhouse construction, at a cost exceeding $45,000,000, there will still undoubtedly be improvements necessary. At present many fish become missing as they move upstream between dams. Others delay for long periods below the dams without apparent reason. There are serious problems that require solution. But with the continued cooperative efforts of the Corps of Engineers and the Northwest fishery agencies, the Columbia River may again be called the "Highway of Salmon," and the salmon's 'right of passage' assured. ■

The radiotracking stations just below the powerhouse provide the means of following the tagged salmon.

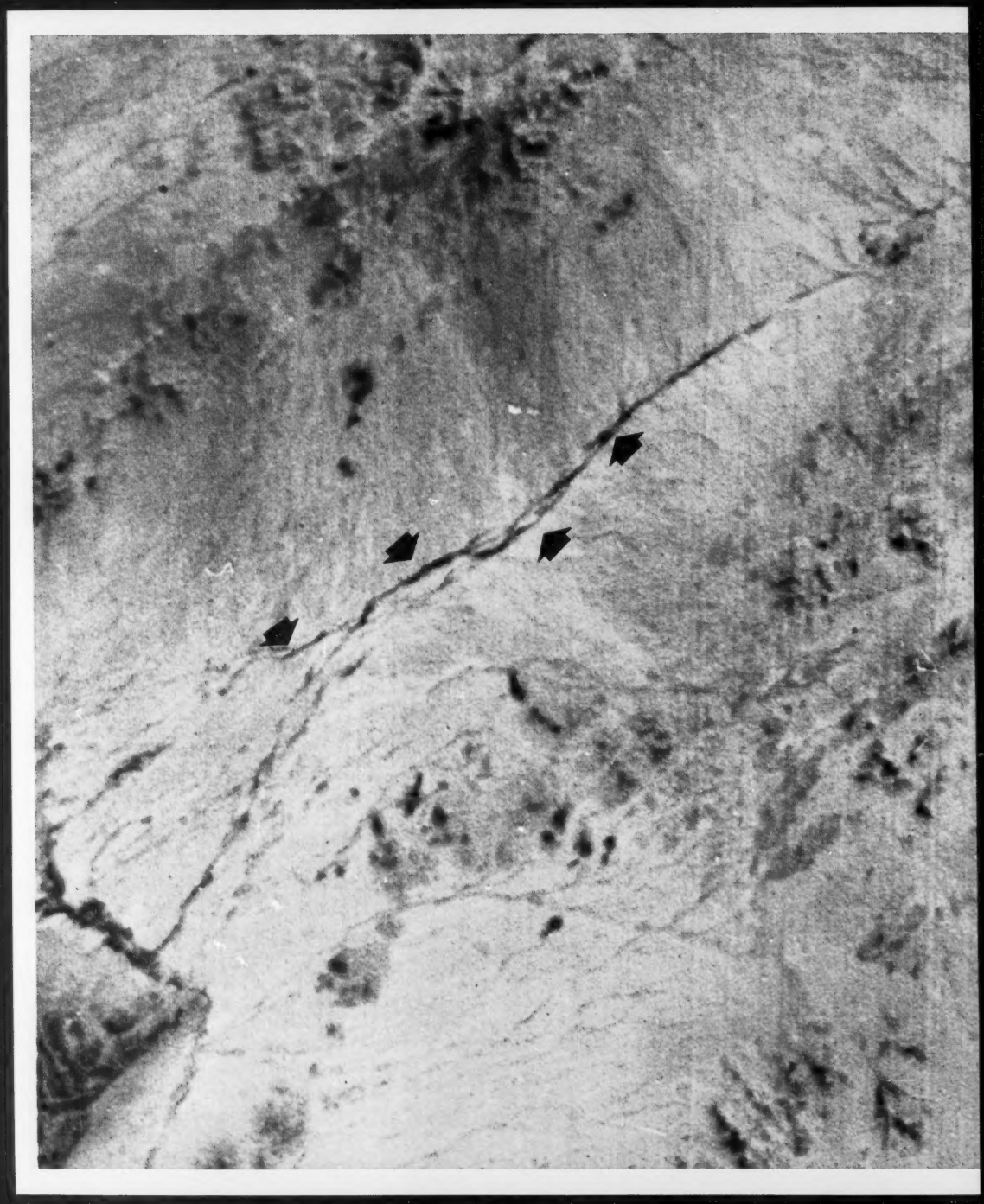
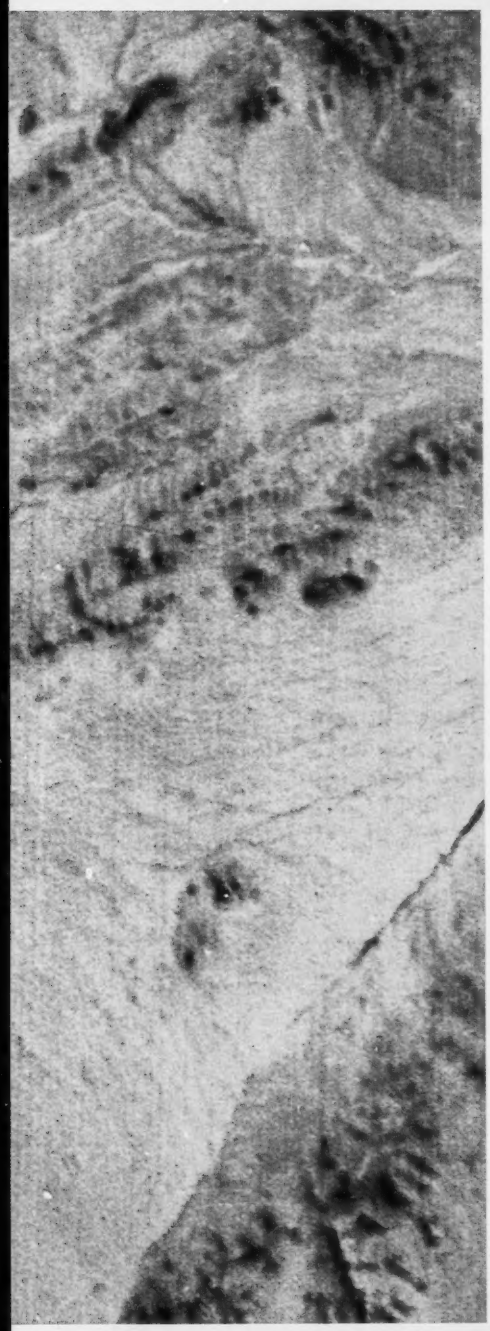


Figure 1. A small stream adjacent to the Papago Indian Reservation, west of Tucson, Arizona at arrows as indicated.

remote sensing

by Charles Croteau



Remote sensing is the science of determining such physical parameters of an object as size, shape, color and temperature without making actual contact with that object. The history of this field of study reaches back to at least the middle of the 19th century, when an officer of the French Corps of Engineers proved that maps could be made from photographs taken by balloon-borne cameras. Improvements in photographic materials and techniques were hastened by the urgency of wartime reconnaissance. By the time of World War II, non-photographic instruments—especially radar—began to be used as adjuncts to photographs. Today, the development of advanced sensing equipment, such as multi-spectral scanners coupled with high-speed computers, promises an enormous body of new information to help us manage our material resources. These newer capabilities are being applied to our national water assets, and, as planned innovations materialize, the pace of applications will accelerate.

Water resources systems planning, design and management are crucial activities at all levels of government. Planning of waterworks and flood control structures—from municipal storm sewers to dam reservoir systems—requires exacting knowledge of such data as average and peak flow rates and storm runoff volumes. River basins are studied to survey water supply and quality, erosion, sedimentation, flooding and irrigation. These parameters, in turn, can be derived from the watershed models developed by the various Federal, regional and local agencies. A primary input for these studies, in addition to hydrologic and meteorologic information, is land use and land cover data that may be derived from remotely sensed parameters.

Remote sensing is also vital in ice and snow mapping, an important activity that provides essential information for water resources management, routing of Great Lakes shipping, and iceberg surveillance. In many parts of the world, snow melt waters provide a major part of the annual water supply, and accurate, early estimates of the snow

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cover can become critically important. The after-effects of the 1977 drought in the Pacific Northwest were overestimated drastically because snow melt water was underestimated. Farmers who heeded the warnings lost money if they didn't plant, or if they invested in expensive, new irrigation systems that, as it turned out, were unnecessary. Erroneous observation was costly.

What are the Observables?

Remote sensing can detect and measure the liquid and solid (snow and ice) forms of water, but the water vapor in the atmosphere hinders our observations and sensing systems must be designed to work around the problem. While most of our water is in lakes, rivers and streams, a considerable volume that is in the ground is equally important to the overall hydrologic cycle and to agriculture. We therefore have an interest in observing both obvious water concentrations, and indirect indications of ground water and soil moisture.

The range of observables detectable by remote sensing is surprisingly large, and much greater than is immediately apparent. This is because the trained observer, seeking signs of water, learns to read indirect signs of its existence in the remotely sensed data. A small stream, too narrow to be directly observable in a satellite image, is detected because of the presence of bankside vegetation. (At arrows in Fig. 1) The possible existence of an underground water source is inferred from study of the geological structure of an area. Water consumption is indicated in photos of irrigated cropland. (Red areas in Fig. 2)

The directly observable parameters of water, however, are somewhat limited. Basically, the surface areas of water bodies may be observed and measured with good accuracy—making remote sensing techniques good sources of "inventory" data. This characteristic applies to snow and ice masses, as well as liquid water, e.g. ice on the Great Lakes has been aircraft-mapped on a daily basis to chart shipping lanes. The easy observability of water has

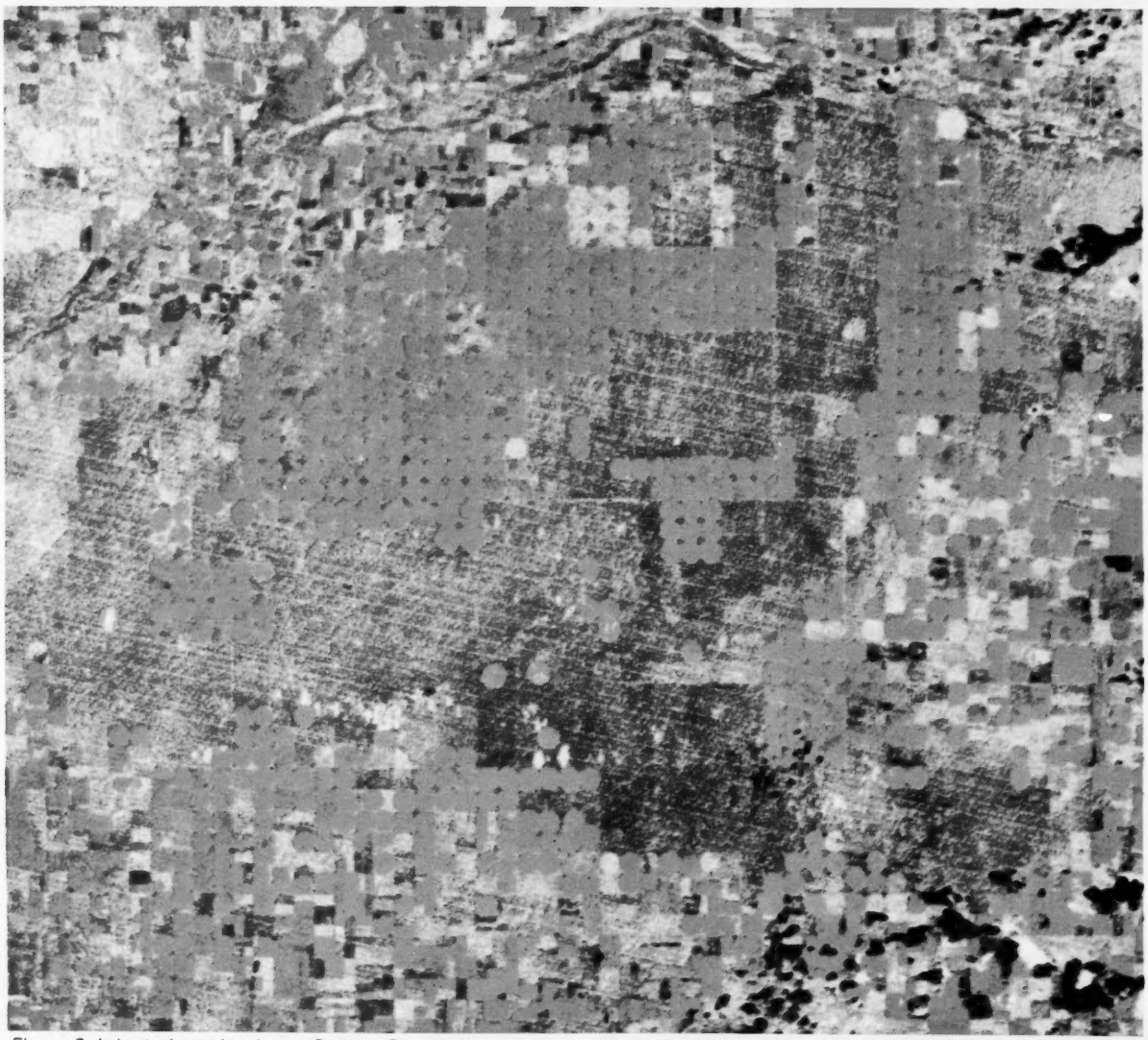
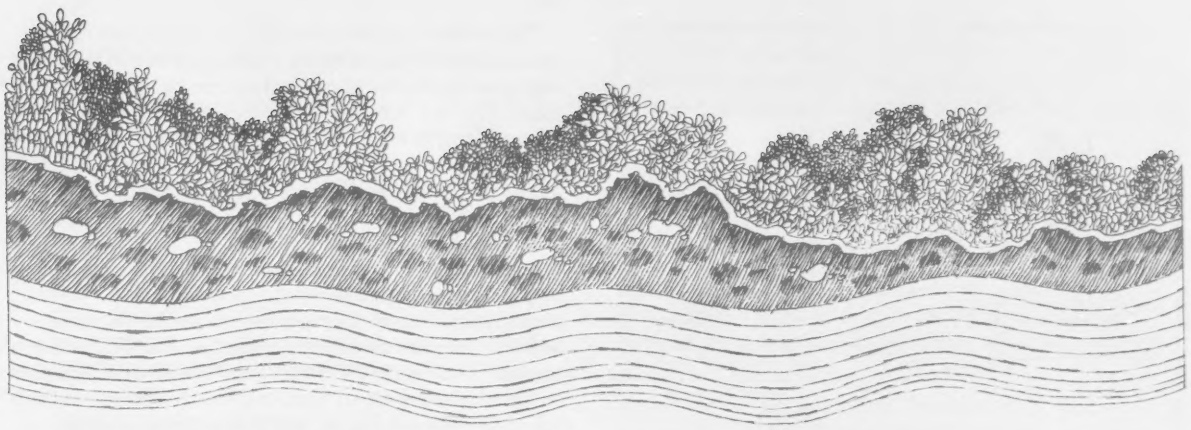


Figure 2. Irrigated cropland near Garden City, Kansas.



TYPICAL MATERIAL RESPONSES

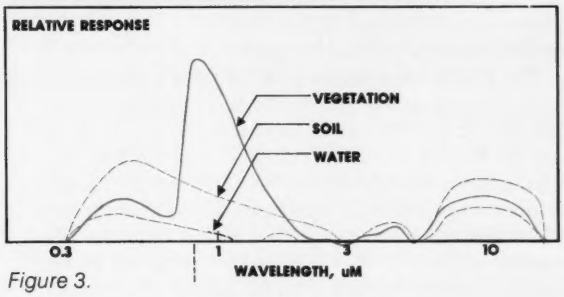


Figure 3.

enabled some application in floodplain mapping. The extent of damaged areas can be measured readily, and mapping thereof successfully accomplished.

Water quality is also difficult to assess remotely. The water quality criteria usually measured are those shown in Table 1, which reports on a study of a Baltimore, Maryland reservoir. In the study, the quantitative values of reflectance seen by a satellite sensor were compared to measurements taken from boats in the reservoirs at the time of satellite overflight. Some values, such as turbidity caused by suspended sediments, correlated well. Other important criteria, such as amounts of dissolved oxygen, required direct observation. Similar studies in other areas have turned up comparable results.

There is significant value, however, in the ability to observe turbidity. Certain chemical pollutants, such as nitrogen or phosphorus ions, move through water attached to sediment particles. The presence of sediment downstream from sources of such chemicals (farm fields or suburban lawns) is a good indicator of potential contamination.

Satellite data and aerial photographs were used in Wisconsin to identify such a pollutant source leading into Prairie Lake. The data showed that the major source of the lake's nutrient loading was Rice Creek, which feeds its northern end. Waste from cows grazing near feeder springs was washed into the creek and then into the lake. When the cows were removed phosphorus levels dropped 94 percent between the summers of 1976 and 77 and wild rice again grew at the creek's mouth.

Remote Sensing Tools

Systems for remote sensing are configured for the job at hand, but generally consist of these components:

The *platform,* which carries the sensing equipment and its necessary power supply and operating hardware. The platform is usually an airplane or a satellite;

The *sensor* itself, which detects and measures the intensity of some position of the electromagnetic spectrum reflected or emitted by the object being studied;

Communications equipment, as necessary, to transmit the sensor signal;

Processing equipment, which converts the transmissions to understandable data—numbers, photos, or graphics. The latter two are self-explanatory.

Platforms

The most commonly used platforms in the remote sensing field are aircraft and satellites, but the definition of remote sensing can be stretched to include a number of fixed, untended data collection platforms around the world that hold sensors "in situ" to measure water temperature, stream flow and other data.

Remote sensing projects make frequent use of aircraft, ranging from single-engine private planes to high flying U2s. Aircraft may carry any of the common sensor types, and by adjusting flight altitude can emphasize resolution or broad-area coverage. Offsetting these advantages are certain practical problems; susceptibility to weather conditions, operating and investment costs, and generally one-time coverage of a target area.

The satellite as a platform has many advantages. Once the satellite is placed in orbit, it operates for years, providing repeated coverage of all areas of the earth, through the changing seasons. This enables development of a data base for every part of the planet's surface.

Sensors

Sensors are classed as active, if, as with radar, they *emit* a signal and receive its reflection from a target. Most sensors used today are passive, depending on *receiving* the electromagnetic radiation reflected or emitted by the earth's surface. The radiation may come from the sun, but also from geothermal sources, such as hot springs, which emit infrared radiation. Fig. 3 shows the portion of the

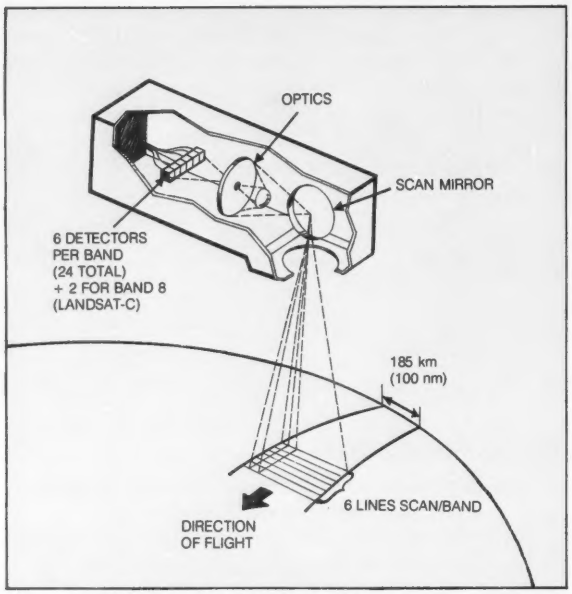


Figure 4. MSS Scanning Arrangement

spectrum from 0.3 to 15 micrometers. The solid line shows the reflectance of water over that range. If water bodies are viewed in the infrared region only, they appear black. However, if sediment is present it will show as a grey tone in the blue color range. This effect is demonstrated in the scanner data sequence in Fig. 5. These scenes of Andros Island in the Bahamas show the changing appearance of water within different spectral bands. More significant effects can be observed through computer processing.

Most sensors, active or passive, are image-makers. Cameras are the most common form and their extensive use has shaped the practices in common use today.

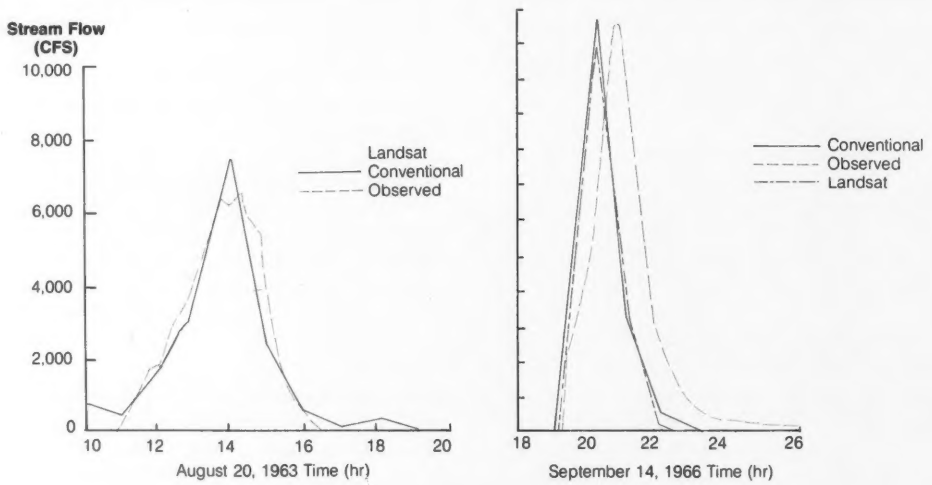
The extensive use of color infrared film in military reconnaissance has led to the current practice of depicting vegetation in shades of red, rather than the natural green tones. This is a consequence of the very bright reflectance of vegetation in the infrared—a phenomenon unseen by the human eye, but very evident in color infrared photos. With a little photoanalysis experience, the eye adjusts to the red tones and they prove to be a sensitive indicator of subtle differences in vegetation.

Scanning sensors are non-photographic, but, since their output may be computer-processed to create a photographic image, they are also classed as imaging devices. They are usually multispectral, and the number of spectral bands varies. The best known scanner is that used on the *Landsat* series of satellites. It is a four or five band design as shown in Fig. 4, which depicts the scanner design. (Since 1972, the Federal government has launched three *Landsats*—two of which are still operating. A much improved multispectral scanner will be aboard the next launch, which is planned for 1981.

The *Landsat* scanner looks at the earth's surface through an oscillating mirror. The steady north-to-south motion of the satellite provides the basic movement along the track and the moving mirror provides the cross motion, or scan. The sensor is electronically switched off during the mirror's return sweep. The truly significant aspect of the scanner is its compatibility with the modern digital computer. The scanner output is readily digitized and available for rapid and inexpensive (though often technically complicated) processing.

Computer Processing

The trend toward computerized, non-photographic sensing systems is accelerating and will be dominant worldwide in the near future. The trend is driven by several factors in addition to the availability of digitized data. Other considerations are the rapidly declining costs



Four Mile Run Hydrographs

of computer hardware and the performance advantages over the photographic medium—at least for civilian resource interests.

The primary advantage of the photograph is its ability to store large amounts of data in a compact format. The disadvantage is in the difficulty of retrieving that data in a quantitative fashion appropriate for measurement, modeling, and analysis. Except for nonquantitative assessment, extraction of data from a photograph is tedious, labor-intensive work. The specialist in image interpretation becomes adept at recognition of features in a photograph, but individual skills are widely variable and are often compartmentalized in technical disciplines such as geology or agriculture. Interpretation results vary with the skills of the interpreters.

In contrast, the digital data provided by a scanning sensor, either satellite or aircraft mounted, is already in the form of numbers representing radiation intensity reflected or emitted by a given area on the earth's surface. (The size of that area depends on sensor and system design.) No data conversion is necessary to gain the speed and power advantages of the computer. If the computer system is interactive, a pictorial display of the data can be provided to a human operator. The operator then can instruct the computer to extract and highlight certain areas on the scene, such as water bodies, and make them appear blue on a color display. This is done easily by the computer, as it is trained to discriminate the low levels of water reflectance in the infrared bands from the stronger contrast of vegetation.

Since the data exist as numbers in a computer and are related to geography in a known way, calculations are quickly and economically done. For example, once a water body has been identified, its size can be calculated as the product of pixel (picture element) size and the pixel count of that water body. The number of separate water bodies can be counted by the computer and each assigned a unique identifier. In that way, an inventory of water bodies can be created by machine and accurate maps drawn. This is just the beginning. The initial inventory represents the start of a data base which exists in digital form. As facts are developed about any given water body, they may be inserted into the digital memory. Some of the facts can be developed from processing of remotely sensed data, but facts developed by water sampling or other direct techniques can also be added to the store of knowledge about the water body. The data base accumulates this information over time and makes it available, on request, in some directly usable form such as a graph or a time series.

This output from the data base is available for monitoring water quality; fulfilling management functions such as reservoir management (sedimentation loads); and analysis such as modeling.

A test on northern Virginia's Four Mile Run explored the use of satellite scanner data as a tool of urban water resources planning. The data were used as input parameters for a hydrologic model of the watershed. The model accepted land cover data derived from the satellite, and simulated stream flows that were in excellent agreement with actually observed peak discharges. Work with related economic data for the watershed also derived estimates of the economic value of flood control facilities.

Remotely sensed data, thus, appears to provide significant reduction in costs and manhours for hydrologic modeling.

An indication of the potential for such savings is shown by a land cover analysis of the entire Great Lakes watershed. More than 75 million acres of land were mapped from *Landsat* data. The areas covered by residences, commercial developments, farms, woodlands and ten other coverage classes were measured and tabulated by watershed district and political subdivision. The cost for this survey was less than .035 cents per acre.

Water Quality Parameters Measured in Liberty Reservoir April 15, 1977

(Ranges from 10 Sample Points)

Table 1

Quality Parameters	Measurement Range (Various sample points)	Landsat Reflectance Measurement Range*
Total Solids (mg/1)	71 to 100	13 to 17
Suspended Solids (mg/1)	0 to 16	15 to 17
Secchi Depth (feet)	2.4 to 10.6	19 to 13
Turbidity (units)	1.5 to 10.5	13 to 23
Total Algae (no./ml)	36 to 203	13 to 15

*On a scale of 0 (dark) to 64 (very bright), blue-green band

How will the Data be Used?

The application of remotely sensed data to engineering projects involves many practical difficulties that usually emerge as dichotomies. For example, readily available data may be inexpensive, but might not be taken at the right time, or with the most desirable sensors. Resolution from a given sensor may not be adequate to see important detail, but the increased processing burden associated with greater resolution may be deemed too costly. Adequate coverage—when, where, how often, how much, etc., also carries significant cost implications. Accuracy and sensitivity of results are important to project planning, but verification of accuracy of data over a large area is expensive and tends to defeat the main reason for using remotely sensed data, which is cost effectiveness in covering areas difficult to see or measure at first hand.

Change Detection

Is the quality of the water in the stream improving or worsening? Is this year's drought more severe than droughts of past years? Extracting information that contributes to answering these questions is a basic task of remote sensing system designers who consider this problem in the general realm of change detection.

The systems designed to perform change detection require registration, or overlay, of data taken at different times, and a data base keyed to geography, to enable

Figure 5. Demonstration of the changing appearance of water within different spectral bands. From left, the blue-green band; red; infra-red (all water appears black); composite.

storage and retrieval of the data. That is, if two or more images of an area, taken at intervals, can be overlayed and referenced to maps, then changes may be noted and related to the map. The data base system could store results of the first data set and recall information for selected geographic areas, as needed, for comparison to results of later data sets. In time, a change history could be compiled to assess long-term trends. Local authorities could determine the extent of changes in beach erosion, for example, and, in many cases, relate the effects to probable causes and possible corrective action.

Applications of remote sensing data usually have a need for data collected over a period of time. For example, the spectral reflectance of a given crop—such as corn—exhibits a regular change during the growing season. This fact is put to use in identifying corn from successive observations of a farm area. For water resources, the changes of interest are more likely to be season to season, or year to year.

The geographical relationship of the data helps in the process of data utilization in that it allows use of non-image data, such as land ownership, soil maps, tax records, and other data that is needed for regional planning.

Future Remote Sensing Systems

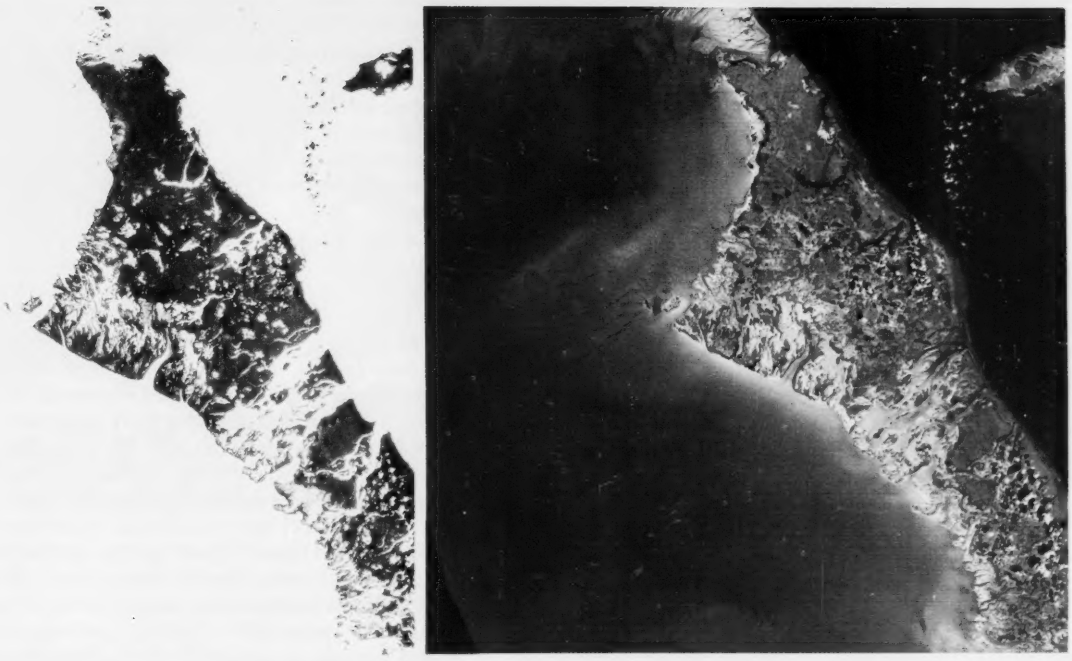
The development of remote sensing technology in the 70s ensured that water monitoring resources will evolve as rapidly as agency budgets will permit. While uncertainties about future budgets make it impossible to forecast precisely the details and timing of new operating systems for water resource management, the overall characteristics are beginning to become apparent.

Future remote sensing systems will become essential elements of larger information systems used for management of multiple resources, with water resources as an essential part. While remotely sensed data sources will continue to present easily interpreted photographic products, the fundamental form of the data will be digital—so that machine processing and satellite communications can be utilized to extract, manipulate and convey data to operational users.

The major increments of progress will result from improved resolution and more frequent coverage. Scientists forsee a pointable sensor of very high resolution and in an orbit providing coverage at two- to five-day intervals. This capability would enable more effective forecasting of water flows. The use of a geosynchronous satellite would permit monitoring of selected dynamic events (at the expense of resolution and wide-area coverage) such as flooded areas or other massive perturbation.

Scanning sensors in the microwave portion of the spectrum, because of their unique ability to penetrate clouds of water vapor, promise new hydrologic applications in the future. The higher resolution provided is needed to observe smaller bodies of water, glaciers and localized ice. Use of microwave sensors will permit penetration of snow cover and enable estimates of depth and total water content. (Common snow packs of interest are three to five feet deep.) *Landsat* data is now used to measure surface area; microwaves will provide depth and density data, and, together they will provide volumetric parameters for run-off estimates.

In the near future, new satellite communications systems will provide improved timeliness in data delivery. The domestic communication satellite "*Domsat*" will be used



in 1981 and subsequent years for rapid, near-to-real time transmission of digital *Landsat* data from the satellite to a ground processor and to a distribution center. Later in that decade the user can expect this technology to provide for his data needs within hours of a real event. The watershed manager can then apply this timely data in his watershed flow model to estimate current conditions over a watershed of hundreds of square miles and, from his computer terminal, make operating decisions affecting parameters within his control.

Other benefits will come from data compatibility. Future systems will be designed with data compatibility as a fundamental consideration. This will mean that data taken of a given area by different sensors and at different times may be accurately registered, or superimposed, with corrections applied for distortion. Changes then may be determined both visually and automatically. This will lead to creation of data storage systems to monitor changes over time.

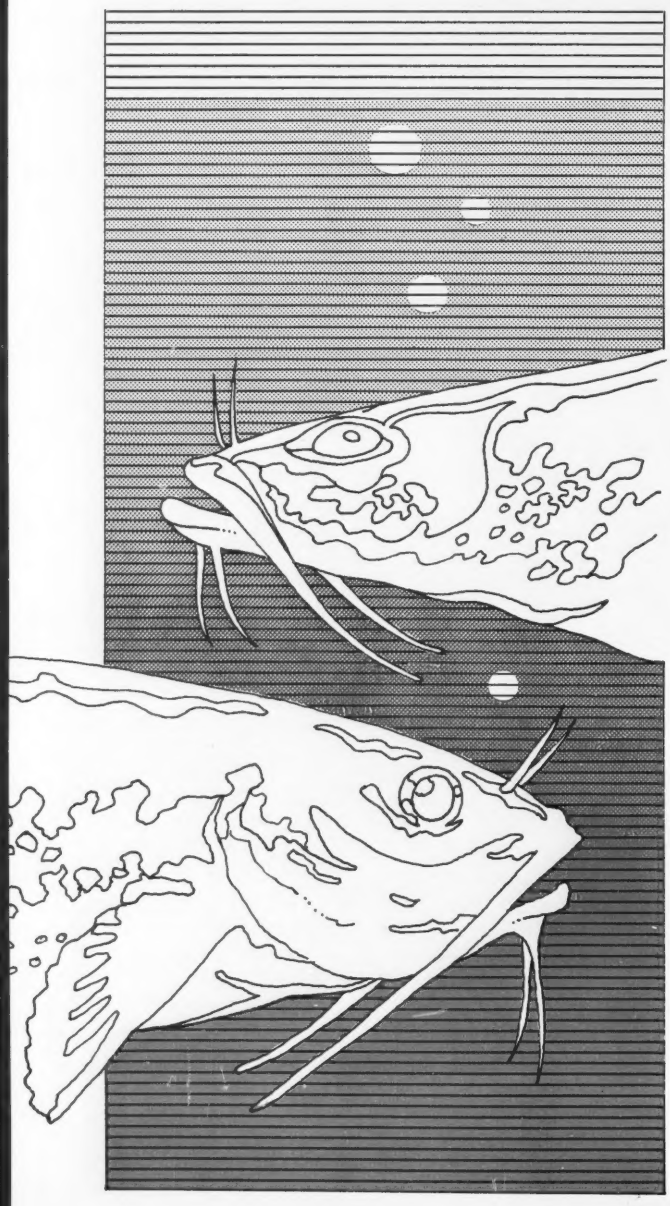
One such system is now assisting the U.S. Army Corps of Engineers in its Dam Safety Inspection Program, where *Landsat* data is used to identify impoundments created by man-man dams. Each impoundment is assigned a unique identifier, and its location, size, and other key attributes are recorded. In time, this methodology will be used to create a complete inventory of selected impoundments, such as important reservoirs, and to record vital parameters such as water quality shown by remote and in situ sensors. Once an inventory is established, the recording of data over time will make available a history of the reservoir, and allow the municipal water department to see if quality is being maintained, for example, or is being adversely affected by changing watershed conditions.

For the long-term future, more advanced processing concepts will evolve to generate information and distribute results rapidly and in a highly cost effective manner. The processing burden will be split, optimally, between the on-board (space) segment and the ground processor. The space processor will be designed to extract essential data for transmission, minimizing processing burdens by intelligent selection, removal of redundancies, on-board classification, etc. The ground processing will be aimed at both dissemination networks and data basing. The overall extractive process, by which information is derived from raw radiometric measurement, is distributed among the space and the ground segment.

As information is generated by space and ground segments, it is accumulated by regionalized and discipline-specific data base systems. The data base systems will be linked by information networks which will provide commercial, governmental, and private users access to information, process it for custom purposes, and make the refined product generally available.

Many of the elements of such a supersystem now exist in conceptual form or as demonstrations. Several states have created data bases which incorporate satellite data. The Bureau of Land Management has developed a long-term plan to create a resource data base to assist its resource managers. Several commercial firms provide custom extractive processing services and many Federal agencies and foreign governments have acquired processing systems. Implementation of the systems concepts described here is largely a matter of technique development and the availability of data communication services in the future. ■

Events, Deeds & Deliberations



Gallatin Begins Aquaculture Project

Warm water discharged from TVA's Gallatin Steam Plant in middle Tennessee will be used by the end of 1979 to produce catfish commercially, the agency has announced. Waste heat, in the form of warm water, is a byproduct of steam-electric generation. This water flows from the heat exchangers where steam is condensed and returned to plant boilers.

Catfish farming in the southeast is presently limited to pond systems. The Gallatin catfish project will use tanks or raceways to raise catfish to commercial size, using warm water from the steam plant to extend the growing season.

"In this project, we intend to develop the technology and management skills necessary to apply power plant waste heat in fish farming," said Wayne A. Hubert, a TVA fisheries biologist in charge of the project. "What we learn here can be applied at other TVA facilities and all across the nation where waste heat from power plants might be used in commercial fish production."

The project will have no effect on operation of the Gallatin Steam Plant. "Power production and plant efficiency will not be affected in any way," Hubert said, "nor will this program have any affect on electric power rates." The project will be paid for with appropriations from Congress, as part of TVA's National Energy Demonstration Program.

The ten raceways should produce 50,000 to 100,000 pounds of catfish a year when operational, which is about the equivalent production of 40 acres of ponds. The catfish raised to commercial size will be marketed through wholesalers. Other fish species with existing or potential commercial value, such as rainbow trout, may be produced at Gallatin.

The basic water source at Gallatin is the Cumberland River, which has a seasonal variation in water temperature between 40 and 78 degrees. "Using the effluent from the plant, we can raise water temperatures 10 to 12 degrees," Hubert said. "This will extend the growing season for catfish by around three months, and the optimum growth temperature can be achieved for most of the summer. Catfish grow best in water around 84 degrees."

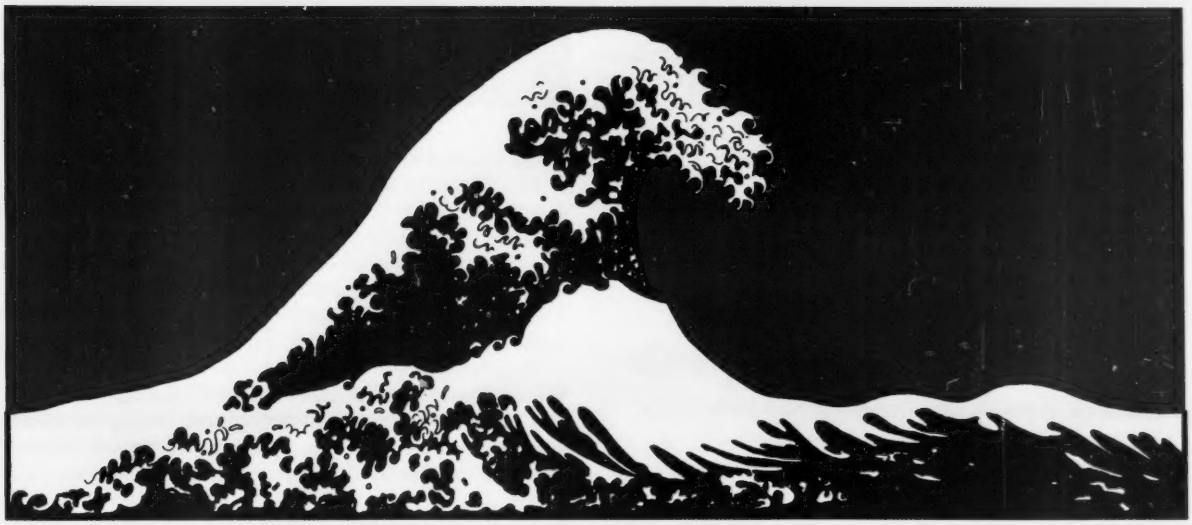
Desalting Sites Selected

Virginia Beach, Virginia, and Alamogordo, New Mexico, have been selected as the first two sites for predesign studies for major desalination demonstration plants, Secretary of the Interior Cecil B. Andrus has announced.

Fifty million dollars have been authorized for five plants to demonstrate state-of-the-art technology for the conversion of saline or other impaired water to usable water.

"Such plants would make water managers and water planners aware of new options for solving problems of water quality or quantity," Andrus said. "Applying advanced technology as part of an operating water system, and in the context of American energy and economic constraints, will provide a basis for judgment of the suitability of these processes."

The Office of Water Research and Technology, which conducts the desalination R&D program, contacted water agency officials in all 50 States, the District of Columbia,



Guam, Puerto Rico, and the Virgin Islands for assistance in identifying candidate sites. The 37 sites proposed were then assessed by an engineering consultant firm and by OWRT water science professionals. Selection of the first two sites was made by OWRT based on its evaluation of desalination technology and the priority needs of the national demonstration program.

Virginia Beach, Virginia, was identified as a seacoast community which could successfully demonstrate the desalination of ocean water, coastal brackish water, or some combination of both. It is anticipated that this part of Virginia will have serious water shortages early in the 1980s unless water supplies can be increased.

Alamogordo, New Mexico, has long-range problems common to locations where brackish water is present in inland aquifers. Successful demonstration of desalination technology to improve the quality of water in the semi-arid areas of our country would be of great benefit to the nation.

Advisory Board Named

In 1970 the Chief of Engineers established an Environmental Advisory Board to provide environmental expertise and experience and to help create mutual understanding and confidence between the Corps, the general public, and the conservation community. Lieutenant General John W. Morris, Chief of Engineers, has announced that four new members had been appointed to the Board. They will join Dr. Gerald J. McLindon, Dean, School of Environmental Design, Louisiana State University, Chairman; and Dr. Stanley A. Caine, former Assistant Secretary for Fish and Wildlife and Parks of the Department of the Interior, and now Professor of Environmental Studies at the University of California, Santa Cruz. The new members are Oliver A. Houck, General Counsel, National Wildlife Federation; Dr. Nicholas L. Clesceri, Director, Freshwater Institute, Rensselaer Polytechnic Institute; Dr. J. Henry Sather, Graduate Dean and Professor of Biology, Western Illinois University; and Dr. Dee Ann Story, Associate Professor of Anthropology, University of Texas.

Energy in Waves

A ship-shaped device floating in the Sea of Japan is gathering wave energy in Japan's first experiment with harnessing waves for power. The 500-ton vessel, named *Kaimei,* is kept afloat by four air compartments in its hull. The wave energy is captured through valve action in 22 bottomless air chambers arranged in pairs, each pair providing air pressure to a turbine and generator combination. The *Kaimei* was designed specifically to work with the 10- to 13-ft. waves of the Japan Sea. It could reportedly produce up to 1375 kw of power. *(Water News and Views)*

Shoreline Erosion Article Offered

Owners of waterfront property may be interested in a shoreline erosion control demonstration project brochure published by the Army Corps of Engineers' Seattle District. The brochure describes a test project at Oak Harbor on the effectiveness of various structures for controlling shoreline erosion from wave action.

Measures the Corps is studying include bulkheads made of used tires or timber, and revetments made of rock-filled gabion mats or sand-cement bags. The two-year test has been in progress for several months, and differences in effectiveness are already apparent.

To obtain a copy of the brochure write: Department of the Army, Seattle District, Corps of Engineers, ATTN: NPSEN-PL-NC, Post Office Box C-3755, Seattle, Washington 98124; telephone (206) 764-3651. ■

Coming Events

Annual Meeting of the Soil Conservation Society of America at Ottawa, Canada, July 29-August 1.

Annual Meeting of the American Institute of Biological Sciences, Oklahoma State University, Stillwater, Oklahoma, August 12-17.

International Research Workshop and Short Course on Coastal Sedimentation Problems, at Texas A&M University, College Station Campus, Texas, August 20-24.

International Symposium on Drought at New Delhi, India, September 2-7.

Annual Meeting of the International Association of Fish and Wildlife Agencies at West Yellowstone, Montana, September 10-12.

Annual Meeting of the American Fisheries Society at West Yellowstone, Montana, September 12-14.

Annual National Waterways Conference at Nashville, Tennessee, September 16-18.

Fifteenth American Water Resources Conference at Las Vegas, Nevada, September 24-28. ■

Bookshelf

Weed Control Methods for River Basin Management, by Dr. Edward O. Gangstad, provides scientific documentation of the means available to control aquatic weeds in river basins and allied waterways. Emphasizing alligatorweed and water hyacinth problems, the 231-page volume addresses all known treatment methodologies. Available from CRC Press, Inc., 2255 Palm Beach Lakes Boulevard, West Palm Beach, FL 33409.

Water Resources and the National Welfare by Walter U. Garstka, consultant in hydrology and visiting professor in natural resources, has been prepared as a broad-aspect reference work to serve as a textbook to assist in the preparation of courses to provide a working knowledge of the subject for those who will be responsible for the management of water and related natural resources. The book consists of 25 sections which include a total of 95 topics. The organization of the book and the contents of the topics are based upon teaching experience at both graduate and undergraduate levels. The presentation of the subject by topics has been found to be useful by consulting engineers. The list of references includes a total of 1465 names. Available from Water Resources Publications, P.O. Box 2841, Littleton, Colorado 80161.

Champlain to Chesapeake: A Canal Era Pictorial Cruise, by William J. McKelvey, Jr., is a journey via historic photographs from Lake Champlain to the Chesapeake Bay. Few of the 485 photographs and illustrations, including ports and boatyards, boatmen and canal workers and actual canal construction, have ever been published. The hardbound, 224-page volume is available from the author at 98 Waldo Avenue, Bloomfield, NJ 07003. ■

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Changes of Command

President Carter has announced the nomination of Michael Blumenfeld to be Assistant Secretary of the Army for Civil Works. Mr. Blumenfeld served in the Army from 1953 to 1956 and was advertising account executive with Benton and Bowles. From 1969 to 1970 he was assistant to the vice president for public affairs of Consolidated Edison Co. and was director of public affairs for New York University from 1973 to 1977. He had been overseeing the Civil Works program, which has included encouraging an effective dialogue between the Corps and environmental groups and formulation of the Army's proposal for a non-federal dam safety program.

Colonel Lee Nunn, Jr., will become Alaska district engineer in June. Nunn has attended the Army War College, and has held key command and staff positions in the Army and the U.S. Air Force. He replaces Colonel George R. Robertson.

Colonel William W. Badger will become district engineer at St. Paul, Minnesota in June. He will succeed Colonel Forrest T. Gay, III. Badger was most recently assigned to the Office, Chief of Engineers in Washington, D.C. as special assistant for foreign programs.

Colonel Vito D. Stipo will become Omaha district engineer in June. He will replace Colonel James W. Ray, who is being assigned as assistant deputy chief of staff, Engineer, U.S. Army Headquarters in Europe. Stipo was the deputy division engineer for the Corp's Missouri River Division, based in Omaha.

Colonel James W. Peck will become Baltimore district engineer in June. He will replace Colonel George K. Withers, Jr., whose next assignment will be announced later. Since 1977, Peck has been assigned to the Office of the Chief of Engineers in Washington, D.C., as an assistant director of civil works.

Colonel James M. Sigler will become Galveston district engineer, also in June. Colonel Sigler, whose most recent assignment was attendance at the Army War College, replaces Colonel Jon C. Vanden Bosch.

In another June reassignment, Colonel Robert H. Ryan becomes district engineer at Mobile. He replaces Colonel Charlie L. Blalock. Colonel Ryan was most recently attending the Industrial College of the Armed Forces. ■

Letters

Editor:
Thanks for sending along the winter issue containing Dan Talhelm's "Fisheries: Dollars & Cents . . . I am pleased that you found some of the pictures suitable for illustrating the article . . . We noticed that some of the fish drawings were a bit peculiar for Great Lakes species, though."
Suzanne Tainter
Associate Editor
Michigan Sea Grant Program

Our artist insists that the peculiar fish are "thus far undiscovered Great Lakes species." She will be lowered repeatedly into Lake Michigan until this ichthyological oversight is corrected—Ed. ■

Water Spectrum marks 10th Anniversary

With this issue, *Water Spectrum* marks the 10th anniversary of its debut as a periodical of water resources management topics.

During the decade, the magazine has grown from less than 40 pages per issue to more than 50, and from an occasional duotone to full process color. It has been published under, and benefitted from, three Chiefs of Engineers and a like number of editors. Mostly staff-written during its infancy, *Water Spectrum* now features the bylines of those in the highest-ranking governmental, scientific and academic positions. The magazine has won numerous communications awards and has been quoted in the Congressional Register. It has gained an international audience.

Its goal is stated inside the front cover: "To serve as a written forum for the open discussion of issues and choices in resolving water resource problems." This goal, however, has served as a springboard and not a restriction. Articles on endangered species, ecological crises, alternative energy sources, and sociological implications have found a place in the magazine—as have the opinions of groups in opposition to certain Corps' policies.

The staff pledges continuance of this totally open forum policy and the publication of an even better *Water Spectrum* in the decade to come.

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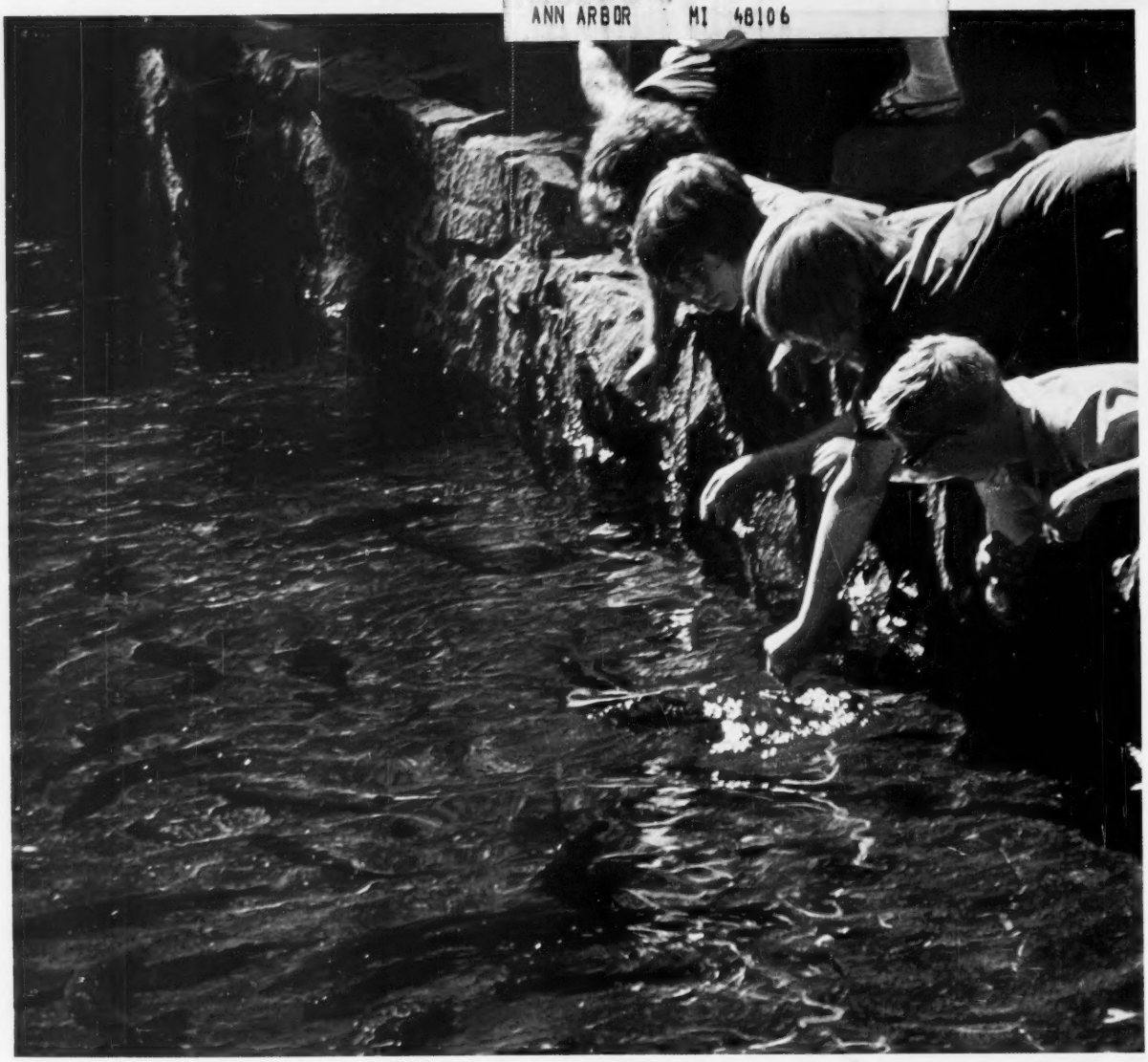
Exciting things are happening at Oregon's Bonneville Da *n spawning run.*
See "Right of Passage" on Page 38. (CofE Photo)